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S. HRG. 99-902

CONTINENTAL SCIENTIFIC DRILLING AND EXPLORATION ACT

HEARING

BEFORE THE

SUBCOMMITTEE ON NATURAL RESOURCES DEVELOPMENT AND PRODUCTION

OF THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

NINETY-NINTH CONGRESS

SECOND SESSION

ON

S. 1026

A BILL TO DIRECT THE COOPERATION OF CERTAIN FEDERAL ENTITIES IN THE IMPLEMENTATION OF THE CONTINENTAL SCIENTIFIC DRILLING PROGRAM

JULY 24, 1986

Printed for the use of the
Committee on Energy and Natural Resources

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S311-10

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CONTINENTAL SCIENTIFIC DRILLING AND EXPLORATION ACT

THURSDAY, JULY 24, 1986

U.S. SENATE,
SUBCOMMITTEE ON NATURAL RESOURCES
DEVELOPMENT AND PRODUCTION,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The subcommittee met, pursuant to notice at 10:12 a.m., in room SD-366, Dirksen Senate Office Building, Hon. John W. Warner presiding.

Present: Senators Warner, Nickles, and Hecht.

Also present: Robert L. Terrell, professional staff member; and Patricia J. Beneke, counsel for the minority.

OPENING STATEMENT OF HON. JOHN W. WARNER, A U.S. SENATOR FROM THE STATE OF VIRGINIA

Senator WARNER. The subcommittee will now open its hearing. I apologize for the delay, but I appeared with the leadership when the Senate opened at 10 o'clock on the floor.

Today the Subcommittee on Natural Resources Development and Production will hear testimony on Senate bill 1026, a bill to direct the cooperation of certain Federal entities in the implementation of the Continental Scientific Drilling Program. S. 1026 was introduced by my distinguished colleague from South Dakota, Senator Pressler, in April of last year. I am pleased that Senator Pressler will either appear this morning or submit his statement. As of this moment, we are not certain as to his schedule.

Other witnesses appearing today represent a distinguished lineup of representatives from the Federal Government, academia, and industry. The committee looks forward to hearing your testimony.

The thrust of the bill would be directed toward developing a basic and more advanced understanding of the Earth's lithosphere in general, and of the structure and lithology of the crust underlying North America specifically. This would be accomplished through the use of the ultimate exploration tool, the drill. I believe, as I am sure most of our witnesses today also share the view, that such efforts could well lead to breakthroughs in such areas as new sources of energy and mineral deposits, responsible waste disposal practices, and advances in the science of predicting earthquakes and volcanic activity.

I am advised that a number of nations have established continental scientific drilling programs, including Canada, France, Belgium,

Japan, West Germany, the United Kingdom, Czechoslovakia, and the Soviet Union. I believe it is appropriate at this time for the United States to undertake a like program.

Today we will receive for the record statements from Senators Lloyd Bentsen of Texas; Mr. Allen Agnew, geological consultant from Oregon; Dr. Melvin Friedman, dean of the College of Geosciences, Texas A&M University; Dr. Robert D. Hatcher, department of geological sciences, University of Tennessee, together with Dr. Richard T. Williams, department of geology, University of South Carolina.

[The text of S. 1026 and prepared statements of Senator Murkowski, Senator Bingaman, Senator Bentsen, Mr. Agnew, Dr. Friedman, Dr. Hatcher, and Dr. Williams referred to follow:]

II

99TH CONGRESS
1ST SESSION

S. 1026

To direct the cooperation of certain Federal entities in the implementation of the Continental Scientific Drilling Program.

IN THE SENATE OF THE UNITED STATES

APRIL 26 (legislative day, APRIL 15), 1985

Mr. PRESSLER introduced the following bill; which was read twice and referred to the Committee on Energy and Natural Resources

---

A BILL

To direct the cooperation of certain Federal entities in the implementation of the Continental Scientific Drilling Program.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Continental Scientific Drilling and Exploration Act".

PURPOSES

SEC. 2. The purpose of this Act is to—

(1) implement section 323 of the joint resolution entitled "Joint Resolution making continuing appropriations for the fiscal year 1985, and for other purposes", approved October 12, 1984 (Public Law 98–

473; 98 Stat. 1875) which supports and encourages the development of a national Continental Scientific Drilling Program;

(2) enhance fundamental understanding of the composition, structure, dynamics, and evolution of the continental crust, and how such processes affect natural phenomena such as earthquakes, volcanic eruptions, transfer of geothermal energy, distribution of mineral deposits, the occurrence of fossil fuels, and the nature and extent of acquifers;

(3) advance basic earth sciences research and technological development;

(4) obtain critical data regarding the earth's crust relating to isolation of hazardous wastes; and

(5) develop a long-range plan for implementation of the Continental Scientific Drilling Program.

FINDINGS

SEC. 3. Congress finds that—

(1) because the earth provides energy, minerals, and water, and is used as a storage medium for municipal, chemical, and nuclear waste, an understanding of the processes and structures in the earth's crust is essential to the well being of the United States;

(2) there is a need for developing long-range plans for a United States Continental Scientific Drilling Program; and

(3) the Continental Scientific Drilling Program would enhance—

(A) understanding of the crustal evolution of the earth and the mountain building processes;

(B) understanding of the mechanisms of earthquakes and volcanic eruptions and the development of improved techniques for prediction;

(C) understanding of the development and utilization of geothermal and other energy sources and the formation of and occurrence of mineral deposits;

(D) understanding of the migration of fluids in the earth's crust for evaluation of waste contamination and the development of more effective techniques for the safe subsurface disposal of hazardous wastes;

(E) understanding and definition of the size, source, and more effective use of acquifers and other water resources; and

(F) evaluation and verification of surface geophysical techniques needed for exploring and monitoring the earth's crust.

IMPLEMENTATION OF CONTINENTAL SCIENTIFIC DRILLING PROGRAM

SEC. 4. The Secretary of the Department of Energy, the Secretary of the Department of the Interior through the

United States Geological Survey, and the Director of the National Science Foundation shall implement the policies of section 323 of the joint resolution entitled "Joint Resolution making continuing appropriations for the fiscal year 1985, and for other purposes", approved October 12, 1984 (Public Law 98-473; 98 Stat. 1875) by—

(1) taking such action as necessary to assure an effective, cooperative effort in furtherance of the Continental Scientific Drilling Program of the United States;

(2) taking all reasonable administrative and financial measures to assure that the Interagency Accord on Continental Scientific Drilling continues to function effectively in support of such program;

(3) assuring the continuing effective operation of the Interagency Coordinating Group to further the objectives of such program;

(4) taking such action to assure that the Interagency Coordinating Group receives appropriate cooperation from any Federal agency that can contribute to the objectives of such program, without adversely affecting any program or activity of such agency; and

(5) acting through the Interagency Coordinating Group, preparing and submitting to the Congress, within one hundred and eighty days after the enactment of this Act a report describing—

(A) long and short-term policy objectives and goals of the United States Continental Scientific Drilling Program;

(B) projected schedules of desirable scientific and engineering events that would advance United States objectives in the Continental Scientific Drilling Program;

(C) to the extent and for the duration that the Interagency Coordinating Group deems practicable, maximum, minimum, and intermediate levels of resources and funding that would be required by each participating Federal agency to carry out events pursuant to subparagraphs (A) and (B) at the various levels of effort;

(D) the scientific, economic, technological, and social benefits expected to be realized through the implementation of such program at each level described in subparagraph (C);

(E) a recommended course for interaction with the international community in a cooperative effort to achieve the goals and purposes of this Act;

(F) the extent of participation or interest shown to date in the Continental Scientific Drilling Program by—

(i) any other governmental agency;

(ii) any academic institution;

(iii) any organization in the private sector; and

(iv) any governmental or other entity in the international community;

(G) a plan to develop benefical cooperative relationships among the entities mentioned in subparagraph (F), to the extent that the Interagency Coordinating Group deems practicable; and

(H) any other information or recommendations that the Interagency Coordinating Group deems appropriate.

Frank H. Murkowski

STATEMENT BY SENATOR FRANK H. MURKOWSKI

SUBCOMMITTEE ON NATURAL RESOURCES

DEVELOPMENT AND PRODUCTION

JULY 24, 1986

MR. CHAIRMAN, I APPRECIATE HAVING THE OPPORTUNITY TO HEAR THE TESTIMONY THAT WILL BE PRESENTED TODAY ON S. 1026.

FOR DECADES WE HAVE CONTINUED TO EXPAND OUR EXPLORATION OF SPACE AND EXAMINE ITS IMPLICATIONS FOR THE FUTURE. SIMILARLY, WE HAVE PUT SIGNIFICANT RESEARCH EFFORTS INTO OUR OCEAN FLOORS AND PLATE TECTONICS. WHAT WE HAVE FAILED TO ADEQUATELY RECOGNIZE THROUGH SCIENTIFIC RESEARCH IS THE VAST POTENTIAL OF THE CONTINENTS THEMSELVES. THE CONTINENTAL CRUST IS STILL RELATIVELY UNEXPLORED TERRITORY THAT POTENTIALLY COULD PROVIDE VAST SUPPLIES OF MINERAL AND ENERGY RESOURCES, AS WELL AS THE IMPORTANT INFORMATION NEEDED TO UNDERSTAND NATURAL PHENOMENA SUCH AS EARTHQUAKES AND VOLCANOES.

ALASKA PLANS TO PARTICIPATE IN THE CONTINENTAL SCIENTIFIC DRILLING PROGRAM INITIALLY THROUGH A PROJECT AT KATMAI ON THE ALASKA PENINSULA. THIS PROJECT WILL INVESTIGATE THE 1912

ERUPTION AT THE VALLEY OF TEN THOUSAND SMOKES, AND THE RELATIONSHIP TO THE KATMAI CLUSTER OF VOLCANOES. THE DEEP EXPLORATION WILL EXPAND OUR UNDERSTANDING OF THE FORCES AT PLAY IN VOLCANOES. THIS INFORMATION WILL BE USEFUL FOR HAZARD ASSESSMENT AND FOR EVALUATING POTENTIAL RESOURCES.

THE KNOWLEDGE TO BE GAINED FROM THE CONTINENTAL SCIENTIFIC DRILLING PROGRAM WILL NO DOUBT HAVE TREMENDOUS IMPLICATIONS FOR OUR SCIENTIFIC UNDERSTANDING OF THE EARTH AND ITS POTENTIAL -- BOTH ITS MYSTERIES, IN THE FORM OF EARTHQUAKES AND VOLCANOES, AND ITS PROMISES, IN ITS SUPPLIES OF RESOURCES. I INTEND TO COSPONSOR S. 1026 AND LOOK FORWARD TO FOLLOWING THE FURTHER DEVELOPMENT OF THE PROGRAM THROUGH THE COOPERATIVE EFFORTS OF FEDERAL AND PRIVATE AGENCIES. THANK YOU, MR. CHAIRMAN.

STATEMENT BY SENATOR JEFF BINGAMAN
SUBCOMMITTEE ON NATURAL RESOURCES DEVELOPMENT AND PRODUCTION
S. 1026/CONTINENTAL SCIENTIFIC DRILLING
JULY 24, 1986

Mr. Chairman I would like to express my support for this important scientific legislation and ask that I be added as a cosponsor.

There is still much to be learned about the continent upon which we live and this legislation would establish a mechanism for exploration of its vast mineral resources. Scientists now know that the continental crust evolved over a long period of time and that its evolution involved a great number and diversity of processes. A more advanced understanding of these processes and of the structure and lithology of the crust underlying North America could result in revolutionary scientific discoveries and should be encouraged.

Thank you Mr. Chairman.

TESTIMONY OF
HONORABLE LLOYD M. BENTSEN
SENATOR OF TEXAS

S. 1026
CONTINENTAL SCIENTIFIC DRILLING AND
EXPLORATION ACT OF 1985

SUBCOMMITTEE ON NATURAL RESOURCES
DEVELOPMENT AND PRODUCTION
COMMITTEE ON ENERGY AND NATURAL RESOURCES
UNITED STATES SENATE

JULY 24, 1986

Mr. Chairman, I am pleased to testify today in support of S. 1026, the Continental Scientific Drilling and Exploration Act of 1985. As a co-sponsor of the bill, I want to take this chance to thank my friend from South Dakota, Senator Larry Pressler, for the wisdom and leadership that he has shown in bringing to our attention a scientific initiative of signal importance. If S. 1026 becomes law, we will make a greater commitment to the Continental Scientific Drilling Program (CSDP) and will continue to use the drill bit and the rotary rig to expand our exploration of "inner space", increasing our knowledge of the planet and gaining broad insight into the geophysical processes that affect the search for resources, the disposal of wastes underground and the effort to predict the occurrence of earthquakes, volcanic eruptions and other natural phenomena. I see S. 1026 as a station on the way to a new frontier whose promises and possibilities are now only dimly understood.

The CSDP, administered jointly by the Department of Energy (DOE), the Department of the Interior (DOI), the National Science Foundation (NSF) and a consortium of many of our finest universities, already has allowed us to make substantial progress in geophysical science. The national scientific community has guided and nutured the CSDP through open and effective peer review of objectives and proposals. The knowledge gained from the shallower holes drilled under the auspices of the CSDP to date is exciting and serves to suggest how much we may achieve if we do more drilling at shallower depths and undertake the exploration of deeper, fundamentally unknown levels of the earth's crust.

S. 1026 is a simple and straightforward bill. It calls for implementation of Section 323 of P.L. 98-473, a provision of law stating that it is the sense of Congress that the CSDP is an important national scientific and commercial endeavor that

should be pursued vigorously by the federal government and the private sector. Basically, S. 1026 directs DOE, DOI and NSF to take action necessary to further the program. Also, it requires that Congress be given a special report that describes the goals and benefits of the program and recommends a course of development. S. 1026 will give us the opportunity and information that we need to channel the CSDP properly in the years ahead.

As a Texan, I can point with pride to the historic role that the petroleum industry has played in advancing geophysical science. Many of my state's best known oilmen in fact are accomplished geophysical scientists in their own right. Much of our knowledge of the earth's crust down to depths of 10,000 to 15,000 feet derives from their work in petroleum exploration and production. Of course, S. 1026 strikes a responsive chord in the petroleum industry not only because of its positive implications for basic geophysical science, but also because it will give oilmen a national laboratory in which they can test the technology for drilling to depths where high pressure, high temperature and corrosive fluids have prevented them from drilling in the past. Just as our space program led to the creation of a technology from which many "spin-offs" resulted, so the CSDP will give the petroleum industry dramatic new tools with which to continue the search for energy reserves.

Our world leadership in geophysical science is being challenged today as never before. In other nations, programs similar to the CSDP are operating on faster schedules and are more ambitious in scope. More than 15 years ago, the Soviet Union saw the strategic advantage of a greater knowledge of the earth's crust. The Soviet plan to use a radical new technology to drill a deep hole in the Kola Peninsula is moving quickly ahead. Indeed, the Soviets have passed the 40,000-foot mark and are preparing to drill four more deep holes in other parts of their country. The Federal Republic of Germany is not far behind. The West Germans have committed themselves to a $200-million deep drilling program and have identified two sites for holes within their borders. Obviously, the race to answer some of the key questions about the earth's crust is rapidly developing into an international demontsration of scientific and engineering skill as well as an international effort to see who will enjoy the strategic economic advantages that technological superiority brings.

The CSDP has as its primary goal the acquisition of new knowledge of the earth. This is knowledge of a kind that can be won only by exploratory drilling. The program envisioned in S. 1026 poses many difficult, but hardly insurmountable,

problems for us. Because it links the ample resources of three federal agencies with the intellectual strength of 33 universities and the "can do" attitude of the petroleum industry, S. 1026 is a bill that contains a prescription for success.

Mr. Chairman, enactment of S. 1026 will be a sign that Congress recognizes the many and varied benefits of the CSDP. The process of planning has been long and thorough. Now is the time to endorse the projects and activities that are essential for success. I urge my colleagues to join me in supporting S. 1026.

Thank you, Mr. Chairman.

REGISTERED ENGINEERING GEOLOGIST, OREGON E123
CERTIFIED GEOLOGIST, INDIANA
CERTIFIED PROFESSIONAL GEOLOGIST, AIPG

MINING GEOLOGY
GROUND-WATER GEOLOGY
ENGINEERING GEOLOGY

ALLEN F. AGNEW

GEOLOGICAL CONSULTANT
3660 NW ROOSEVELT DRIVE, CORVALLIS, OR 97330
Phone 503-752-0533

April 2, 1986

Hon. Mark O. Hatfield
U. S. Senate
SH-711
Washington, D. 20510

Re: S.1026, Continental Scientific Drilling

Dear Senator Hatfield:

I understand that the Senate Committee on Energy and Natural Resources has scheduled a hearing on S.1026, the Continental Scientific Drilling and Exploration Act, for July 24, 1986, before the Subcommittee on Natural Resources Development and Production.

In my 45-years as a geologist, teaching and research about the earth has been my career. Before retiring from the Congressional Research Service in 1981, where I was Senior Specialist in Environmental Policy for a decade and dealt with mineral and water-resource issues, I attempted to answer questions from Members and their staffs about the Earth that we inhabit. Today I am continuing in that information-transfer mode, through my teaching at Oregon State University.

At and near the surface of the Earth we have learned from techniques of exploration and excavation, using shallow drilling and geophysics, by directly examining the materials beneath our feet. However, as we go deeper into the Earth (our limit has been two miles deep for excavation, and about five miles for drilling), we must use geophysical methods to indirectly sense what is down there.

We need a Congressionally authorized and funded program that will ensure the growth and maturing of this extremely important effort. In times of tight budgets and multiple national priorities, it is understandably difficult to embark upon such a program. However, to look below the continents on which we reside will be far less expensive than our outward-looking space program, which has been so valuable.

I urge you to consider carefully and thoroughly the provisions of S.1026, the Continental Scientific Drilling and Exploration Act, and to press your colleagues to adopt it or similar legislation that will enable us to embark upon such a worthwhile program. (Statement attached)

Sincerely

Allen F. Agnew

Allen F. Agnew
Geological Consultant

Statement in Support of S.1026

by Allen F. Agnew, Geological Consultant, Corvallis, Oregon

April 2, 1986

Our Ignorance of the Earth's Continental Crust

The radius of our increasing knowledge about the Earth corresponds to the circumference of our ignorance about it. This is particularly true as we leave the thin shell that we are most familiar with, and delve deeper into the causes of our geologic resources and hazards--which accompany geologic processes and the products that they create.

I teach courses in engineering geology and hydrogeology at Oregon State University, wherein we deal with the use of the Earth and its resources by people, and the hazards of our misuse (hazardous waste disposal) and of natural processes (volcanoes and earthquakes). My 45-year career has been spent as a geologist teacher, researcher, and administrator. Before retiring from the Congressional Research Service in 1981, where I was Senior Specialist in Environmental Policy for a decade and dealt with mineral and water-resource issues, I attempted to answer questions from Members and Committees and their staffs about the Earth we inhabit.

At and near the surface of the Earth we have learned from direct examination using our techniques of exploration and excavation, with shallow drilling and geophysics. However, as we go deeper into the Earth for knowledge (our limit has been two miles deep for excavation, and five miles or so for drilling), we must use geophysical methods as our means of remote sensing. This requires increasingly sophisticated techniques, technology, and equipment, as we attempt to sense indirectly the substance of the deeper part of the Earth's crust via geophysics, and directly via drilling. But, in this

deeper probing, we must combat and conquer the physical and chemical problems that are caused by extremely high temperatures and pressures at those greater depths, and also deal with the corrosive fluids encountered.

Our Scientific and Engineering Resources

Fortunately, the U. S. possesses capable scientists and engineers who are able to undertake such efforts. Acquisition of fundamental knowledge, however, is often expensive. Thus Federal governments, both in the U. S. and abroad, provide the seed money and program direction for such efforts; the U. S. S. R. has made admirable strides in deep-drilling techniques and technology in recent years, as we in the U. S. have learned from information that they are willing to share through scientific channels, and we are having to play catch-up ball.

Also fortunately, U. S. industry has been willing to invest substantial resources from the private sector in planning and carrying out initial steps in our entry into this challenging and exciting field--whose payoff in new knowledge can be huge, as we look to the future.

Over the past decade, forward-thinking scientists and engineers in academia have struggled to provide the seed for such a U. S. program, largely with help from the National Science Foundation, the Department of Energy, and the Department of the Interior's Geological Survey.

Need for Concerted Effort

What we need now is a Congressionally authorized and funded program that will ensure the growth and maturing of this extremely important effort. In times of tight budgets and multiple national

priorities, it is understandably difficult to embark upon such a program. However, to look below the continents on which we reside will be far less expensive than the Space program, which has looked outward into our solar system and provided us with so much knowledge. Furthermore, the cost of the Continental Scientific Drilling Program today can be further reduced by stretching it out, or staging it.

The Continental Scientific Drilling Program is not one for esoteric scientists; rather, it is one that will benefit all U. S. citizens because of the answers it will provide to unanswered questions about our Earth--which enables us to experience the joy of living, but at the same time exposes us to the hazards of our ignorance about the processes that are continually changing the Earth and causing us problems.

S.1026

S.1026 would call upon the Interagency Coordinating Group to submit a study to the Congress, defining detailed goals and objectives of a Continental Scientific Drilling Program, and recommending a program of action. I urge you and your colleagues to consider S.1026 carefully and thoroughly, and to adopt it or similar legislation that will enable us to embark upon such a worthwhile effort.

Thank you for your consideration of my views on this important piece of legislation.

STATEMENT OF

DR. MELVIN FRIEDMAN
DEAN OF THE COLLEGE OF GEOSCIENCES
TEXAS A&M UNIVERSITY
(409) 845-3651

BEFORE THE
SUBCOMMITTEE ON NATURAL RESOURCES
DEVELOPMENT AND PRODUCTION
UNITED STATES SENATE

JULY 24, 1986
SUBMISSION-FOR-THE-RECORD

THANK YOU LADIES AND GENTLEMEN FOR THIS OPPORTUNITY TO EXPRESS MY THOUGHTS IN SUPPORT OF THE CONTINENTAL SCIENTIFIC DRILLING PROGRAM, S. 1026. BELOW I PROVIDE A RATIONALE FOR CSDP BASED ON ITS BENEFIT TO THE NATION, THE STATE OF TEXAS, AND TEXAS A&M UNIVERSITY.

THE PROGRAM FOR GAINING A BETTER UNDERSTANDING OF THE COMPOSITION AND STRUCTURE OF THE EARTH'S CONTINENTAL CRUST THROUGH SCIENTIFIC DRILLING IS A NECESSARY AND ATTRACTIVE INVESTMENT OF RESEARCH FUNDS IN THAT:

1. KNOWLEDGE GAINED WILL BE IMPORTANT TO A HOST OF SOCIETAL NEEDS SUCH AS EARTHQUAKE HAZARD REDUCTION, ISOLATED STORAGE OF NUCLEAR AND OTHER WASTES, SITING OF DAMS, TUNNELS, POWER PLANTS AND OTHER MAJOR STRUCTURES, AND OUR NATURAL RESOURCE BASE (PARTICULARLY OUR FOSSIL AND GEOTHERMAL ENERGY AND NON-FERROUS METALS);
2. GEOLOGISTS AND GEOPHYSICISTS HAVE INVESTIGATED THE CONTINENTAL CRUST SUFFICIENTLY THROUGH SURFACE EXPOSURES, IN DEEP MINES, AND REMOTELY THROUGH GEOPHYSICAL SURVEYS TO PINPOINT SPECIFIC DRILLING SITES TO GAIN MAXIMUM INFORMATION PER DRILLING COST;
3. AT THIS TIME OF DEPRESSED DRILLING FOR OIL AND GAS, NOT ONLY WILL SCIENTIFIC DRILLING CAUSE ECONOMIC ACTIVITY BADLY NEEDED BY THE INDUSTRY, BUT DRILLING COSTS FOR THE PROGRAM WILL BE MINIMAL;
4. TECHNICAL AND SCIENTIFIC NEEDS OF THE DRILLING PROGRAM AND FOR THE ASSOCIATED CORING AND GEOPHYSICAL LOGGING WILL STIMULATE RESEARCH AND DEVELOPMENT THAT WILL KEEP OUR DOMESTIC DRILLING AND WELL-SERVICE INDUSTRIES IN THE FOREFRONT OF TECHNOLOGICAL ADVANCES; AND
5. SCIENTIFICALLY, THE CONTINENTAL CRUST REMAINS AS ONE OF THE LAST MAJOR FRONTIERS IN OUR QUEST TO UNDERSTAND THE EVOLUTION OF OUR PLANET.

FOR THESE VERY SAME REASONS, OUR COLLEAGUES IN THE USSR HAVE BEEN DRILLING THE WORLD'S DEEPEST BOREHOLE (>7.5 MILES, KOLA PENINSULA, 250 MILES NORTH OF THE ARCTIC CIRCLE) AND HAVE STARTED ANOTHER MAJOR PROJECT, KNOWN AS THE SAALTY WELL, PROJECTED TO 9.5 MILES DEPTH NEAR THE CASPIAN SEA. WEST GERMANY HAS RECENTLY COMMITTED $140,000,000 TO A DEEP DRILLING SCIENTIFIC PROJECT - A PROJECTED 9-MILE-DEEP BOREHOLE IN THE BLACK FOREST REGION.

FOR THESE VERY SAME REASONS, OUR DEPARTMENT OF ENERGY, USGS AND NSF HAVE SIGNED AN ACCORD TO WORK TOGETHER TO PROMOTE A DOMESTIC CSDP. ORGANIZATIONAL STRUCTURES ARE IN PLACE TO (A) SCIENTIFICALLY GUIDE THE CSDP, (B) EFFECT THE NECESSARY TECHNOLOGY TRANSFERS FOR DRILLING, CORING AND LOGGING, (C) CONTRACT FOR DRILL RIGS, AND (D) CURATE CORES AND DATA TO ASSURE THAT EASY YET ORDERLY ACCESS IS AVAILABLE TO ALL SCIENTISTS. PROJECTS TO DATE AT THE SALTON SEA AND MINOR BOREHOLES IN THE VOLCANIC TERRAIN OF EASTERN CALIFORNIA HAVE BEEN FINANCIALLY MODEST BEGINNINGS WITH DEMONSTRABLE SCIENTIFIC REWARD. CURRENT PLANS CALL FOR DRILLING A LOCATION ALONG THE SAN ANDREAS FAULT IN CALIFORNIA (TO INVESTIGATE AN ACTIVE SEISMOGENIC FAULT), AT CREED, COLORADO (TO EXPLORE THE TOP OF AN ACTIVE HYDROTHERMAL/MINERALIZED REGION), AND FOR SEVERAL RELATIVELY LOW-COST, SHALLOW BOREHOLES IN THE MID-CONTINENT REGION TO LEARN ABOUT THE COMPOSITION AND PROPERTIES OF THE TOP OF THE NORTH AMERICAN "STABLE PLATFORM". THESE ARE MODEST EFFORTS CONSISTENT WITH THE CURRENT LEAN BUDGET.

<u>UNLESS WE GAIN YOUR SUPPORT, HOWEVER, MAJOR PROJECTS, FROM WHICH THE FULL IMPACT OF CSDP WILL BE DERIVED, WILL NOT BE POSSIBLE.</u>

MUCH HAS BEEN WRITTEN ABOUT THE SCIENTIFIC VALUE AND IMPORTANCE OF CSDP. HERE I WOULD LIKE TO EMPHASIZE ITS VALUE TO THE NATION, THE STATE OF TEXAS,

AND TO TEXAS A&M UNIVERSITY.

MAJOR BENEFITS TO THE NATION:

A. THE RUSSIAN KOLA BOREHOLE IS TO CONTINENTAL SCIENTIFIC INVESTIGATION WHAT SPUTNIK WAS TO THE NATION'S SPACE PROGRAM. NOT ONLY HAS RUSSIA AND WILL WEST GERMANY GAIN THE INTERNATIONAL PRESTIGE OF CARRYING ON SUCH PROGRAMS, BUT THEIR DRILLING INDUSTRIES WILL GAIN THE REPUTATION OF BEING SUPERIOR. BY OUR INVESTING IN A SIMILAR PROGRAM AND AT A SIMILAR SCALE, OUR DRILLING AND WELL-SERVICE INDUSTRIES WILL BE KEPT AT THE CUTTING EDGE OF TECHNOLOGY AND OUR EARTH SCIENTISTS WILL REMAIN AT THE FOREFRONT OF THE GEOLOGY AND GEOPHYSICS OF THE CONTINENTAL CRUST.

B. THROUGH THE SCIENTIFIC FACTS THAT WOULD BE LEARNED ABOUT THE EARTH'S CONTINENTAL CRUST OUR GEOSCIENTISTS WOULD BE BETTER EQUIPPED TO SOLVE MANY OF THE SOCIETAL PROBLEMS MENTIONED ABOVE DEALING WITH THE WORKS OF MAN AND HIS IMPACT ON THIS ENVIRONMENT.

MAJOR BENEFITS TO THE STATE OF TEXAS:

A. SINCE A SIGNIFICANT PERCENTAGE OF THE DRILLING AND WELL-SERVICE INDUSTRY IS CENTERED IN TEXAS, THE STATE AND ITS PEOPLE CANNOT HELP BUT GAIN FROM CSDP DIRECTLY THROUGH JOBS AND CONTRACTED DRILL RIGS AND CORRESPONDING WELL-SERVICE, BUT ALSO THROUGH RESEARCH AND DEVELOPMENT PROJECTS REQUIRED TO FACILITATE THE TECHNOLOGIES OF THE PROGRAM.

B. MAJOR PROGRAMS SUCH AS CSDP HAVE ASSOCIATED WITH THEM FUNDS SET ASIDE TO SUPPORT INDIVIDUAL INVESTIGATORS AND THEIR PROJECTS MADE POSSIBLE BY THE DRILLING OF A SUITABLE BOREHOLE. GEOSCIENTISTS THROUGHOUT THE STATE WILL BE SUBMITTING PROPOSALS, MANY OF WHICH WILL BE FUNDED BY THE VARIOUS FEDERAL AGENCIES. THIS WILL BRING NEW FUNDS TO THE STATE WHICH

THEMSELVES MAKE A SUBSTANTIAL CONTRIBUTION TO THE ECONOMY OF THE STATE.

C. SEVERAL DRILLING PROJECTS HAVE AND WILL BE PROPOSED FOR SITES IN TEXAS. WE WILL GAIN FROM THE SITE SPECIFIC SCIENTIFIC DISCOVERIES FROM SUCH BOREHOLES AND THE LOCAL BUSINESSES AND SUPPLIERS WILL BENEFIT DIRECTLY.

BENEFITS TO TEXAS A&M UNIVERSITY INCLUDE:

A. WE ALREADY ARE WELL-PLACED IN THE ORGANIZATIONAL AND MANAGERIAL STRUCTURE OF DOSECC (THE NSF-SPONSORED ORGANIZATION TO GUIDE EXPENDITURE OF NSF FUNDS FOR THE CSDP, AND FOR WHICH WE ARE A FOUNDING INSTITUTION - DOSECC STANDS FOR DEEP OBSERVATION AND SAMPLING OF THE EARTH'S CONTINENTAL CRUST). I AM A MEMBER OF THE BOARD OF DIRECTORS AND DR. EARL R. HOSKINS, HEAD, DEPARTMENT OF GEOPHYSICS, IS A MEMBER OF THEIR SCIENCE ADVISORY COUNCIL. WERE DOCECC'S BUDGET TO INCREASE, SO TOO WOULD THE PROSPECTS OF OUR GEOSCIENTISTS TO GAIN A SIGNIFICANT SHARE OF THE RESEARCH AND MANAGERIAL RESPONSIBILITY. OUR EXCELLENT REPUTATION AS SCIENCE OPERATOR FOR THE OCEAN DRILLING PROGRAM, A $30-M PER YEAR WORLD-WIDE DRILLING EFFORT, AND OUR GOOD CONTACTS WITH THE DRILLING INDUSTRY WILL ENABLE US TO BID FOR SIGNIFICANT SCIENTIFIC AND OPERATIONAL ROLES WITHIN CSDP.

B. WE HAVE ON OUR FACULTY SEVERAL INDIVIDUALS WHO HAVE THE EXPERTISE AND SCIENTIFIC REPUTATION TO SUBMIT SUCCESSFUL PROPOSALS FOR THE SCIENTIFIC STUDY OF CORES FROM CSDP BOREHOLES AND TO CONDUCT DOWN-HOLE SCIENTIFIC EXPERIMENTS IN THOSE BOREHOLES. WE WOULD THUS BE PROVIDING POTENTIAL SOURCES OF RESEARCH FUNDS FOR THE FACULTY IN A CLIMATE OF OTHERWISE DIMINISHED OPPORTUNITIES.

C. PERHAPS MORE IMPORTANT, OVERALL, WE ARE ASSOCIATED IN COMMON CAUSE WITH SOME OF THE MOST PRESTIGIOUS AND QUALITY RESEARCH UNIVERSITIES IN THE

LAND. NOT ONLY WILL CSDP BE A GREAT BOON TO THE EARTH SCIENCE COMMUNITY IN GENERAL, BUT WE WILL BENEFIT DISPROPORTIONATELY BY TAKING LEADERSHIP ROLES AND BY OUR ASSOCIATION WITH THE EFFORT.

DR. MEL FRIEDMAN, DEAN
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Testimony to

Subcommittee on Natural Resources Development and Production,

Senate Committee on Energy and Natural Resources

in support of Senate Bill S. 1026

Continental Scientific Drilling Program and Exploration Act of 1985

by

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Our purpose here is to indicate our strong support for the proposed Continental Scientific Drilling Program and to discuss one of the projects that might be undertaken as the first ultradeep drill hole project in the program. This project, the Appalachian Ultradeep Core Hole (ADCOH) Project, was identified by the National Academy of Sciences Continental Scientific Drilling Committee in 1984 as the ultradeep hole that should be undertaken first in a U.S. Continental Scientific Drilling Program.

MOUNTAIN CHAINS AND CONTINENTAL CRUST

Man's fascination with mountains and their origins extends back to classical times. At some time we realized that they occur in linear chains coursing for thousands of miles across the continents. Later we recognized that the younger mountain

chains occur near the edges of the present continents and the deeply eroded roots of very old mountain chains are more centrally located in the continents. The plate tectonics theory, formulated in the early 1960s, for the first time provided earth scientists with a unified framework that related the evolution of continents and ocean basins to processes operating in the interior of the earth. It was also quickly recognized that the same processes that drive plate motion are directly responsible for the accumulation of the mineral wealth and fuels of the earth.

A corollary to plate tectonics theory is the integral role of the mountain building process in the evolution of continental crust. Mountain chains result from the plate tectonics-driven collisional processes involving continent-continent, island arc-continent, and oceanic crust-continent collisions. One of the largest and probably least well understood of these processes involves the formation of very large thin "crystalline thrust" sheets of crustal rocks pushed over a continental margin during head-on collision of two continents. These huge sheets are moved hundreds of miles inland from the collision zone, thicken the crust and form basins beyond their leading edges which may accumulate hydrocarbons. Crystalline thrust sheets occur in the Alps, Scotland, the Cordillera of western North America, in Scandinavia and the Appalchians.

Various indirect geophysical methods, including seismic refraction and reflection, provide important and useful images of crustal structure. Yet these techniques are but imprecise means of projecting largely two-dimensional surface geologic data to significant depths. Ultradeep scientific core drilling to depths of 5 to 8 miles (8 to 12 km) in carefully selected localities to maximize yield of data will enable gathering of more precise information on crustal structure, calibrations of geophysical techniques, and extrapolations of surface geologic data. Ultradeep and deep drill holes will also permit much-needed refinement of models of stresses in the crust, which have a direct bearing on our abilities to understand and predict earthquakes, and heat sources/thermal processes in the crust, which are directly related to our understanding of geothermal energy and hydrocarbon accumulations and movement in the crust. Continental scientific drilling will become a much

needed window of "ground truth" into the third dimension of the crust, which is presently accessible only by indirect means yielding useful but unconstrained interpretations. The amount of useful knowledge that has been produced to date in the Ocean Drilling Program bears out the immense utility of scientific drilling. Since the oceans are much less complex than the continents, largely owing to their relative youth, the proposed Continental Drilling Program will doubtlessly provide a number of major breakthroughs in our knowledge of continental structure and evolution, and perhaps even the discovery of new principles and the requisite abandonment of existing concepts. Our present state of knowledge of the third dimension of the continental crust is probably less than our knowledge of the back side of the moon, which is not visible from the earth.

THE ADCOH PROJECT

The huge thrust sheet in the Appalachians (Fig. 1) is probably the best preserved of the large crystalline thrust sheets in the world that would be accessible with the drill using largely existing technology. The ADCOH Project has as its principal goal the exploration of the vertical dimension of this sheet using the drill to explore its anatomy and investigate the formation of several kinds of fault rocks (Fig. 2). In addition, stresses at mid-crustal depths, fluid migration in the middle crust, the calibration of seismic reflectors of many kinds, crustal thermal processes and the sources of radiogenic heat, hydrocarbon evolution and migration beneath these sheets, ultradeep drilling/coring technology, and many other fundamental investigations will be undertaken in the ADCOH Project. It is also intended that this project not end with the drilling of the hole and recovery of core. There will be an unsurpassed scientific effort here which will enable the establishment of a long term Crustal Observatory and International Laboratory for Crustal Studies, combining the knowledge gained from the third dimensional investigations with studies conducted on the surface during the past two decades.

The ADCOH Project will have a direct impact on the people of the U.S. and the southeastern region. Studies of mid-crustal

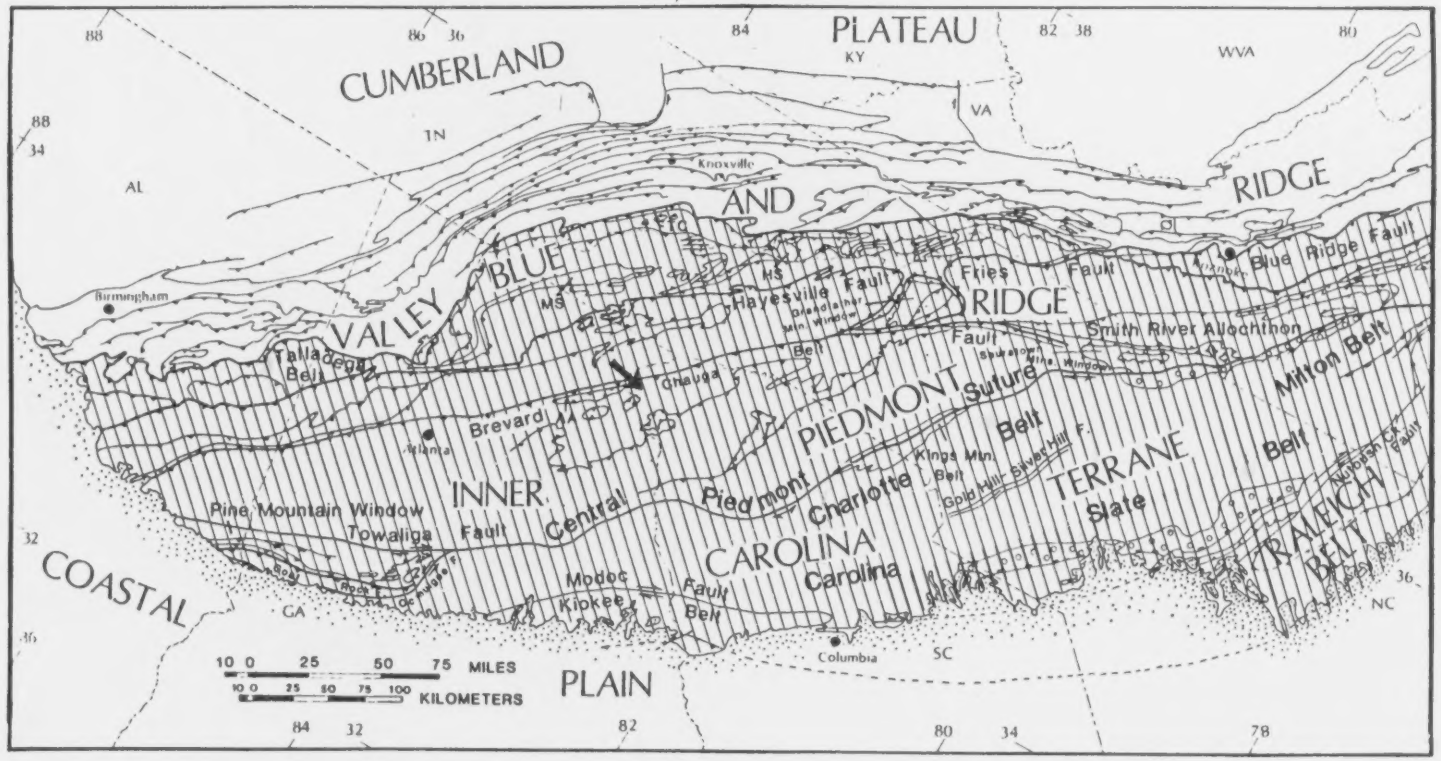

Figure 1. Geologic subdivisions of the southern Appalachians. Heavy arrow in the center of the map is the location of the proposed ADCOH Project in South Carolina and Georgia. The line pattern overlay indicates the approximate known extent of the Blue Ridge-Piedmont crystalline thrust sheet determined from surface geologic and subsurface geophysical imaging techniques.

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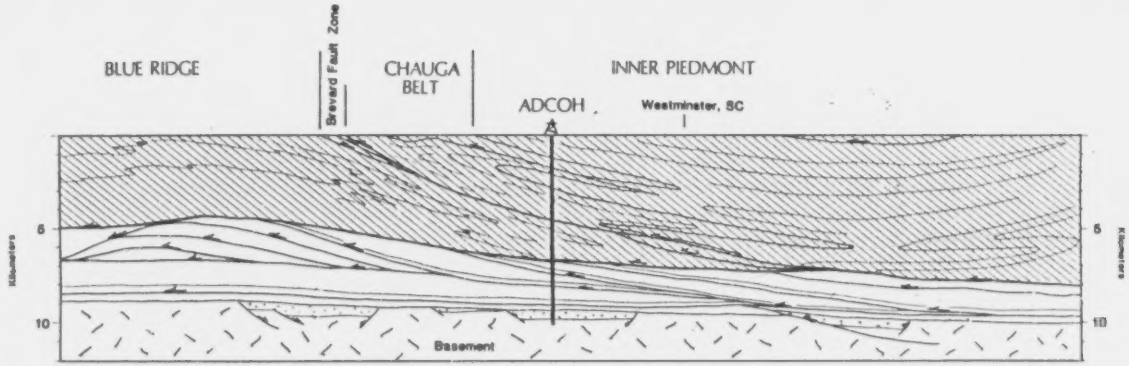


Figure 2. Geologic cross section through the ADCOH site study area showing the interpretation of the crustal structure and the location of the proposed ultradeep hole. The heavy lines are faults and the arrows indicate sense of movement. The light stippled areas are sedimentary rocks deposited in 700 million year old extensional basins. The line pattern overlay is the crystalline thrust sheet which was emplaced about 290 million years ago.

stresses will provide information on what causes earthquakes, additional data to help constrain design of critical engineering structures, hazards in coastal areas and even the building codes for routine construction. Drilling/coring technology for ultradeep drilling in crystalline rocks to be developed here will provide the U.S. once again with the competitive edge in bit and core barrel design.

A short booklet explaining the purposes and goals of the proposed ADCOH Project is appended to this testimony.

COSTS

All involved with the proposed Continental Scientific Drilling Program are very much aware of the desire to hold down costs. While the costs of this proposed program are not insignificant, they are modest in comparison with the costs of comparable programs in the other basic sciences, such as the orbiting telescope, the proposed lunar base and research related to harnessing nuclear fusion. The costs of the scientific investigations related to the proposed Continental Scientific Drilling Program should probably not exceed one quarter to one third the costs of drilling.

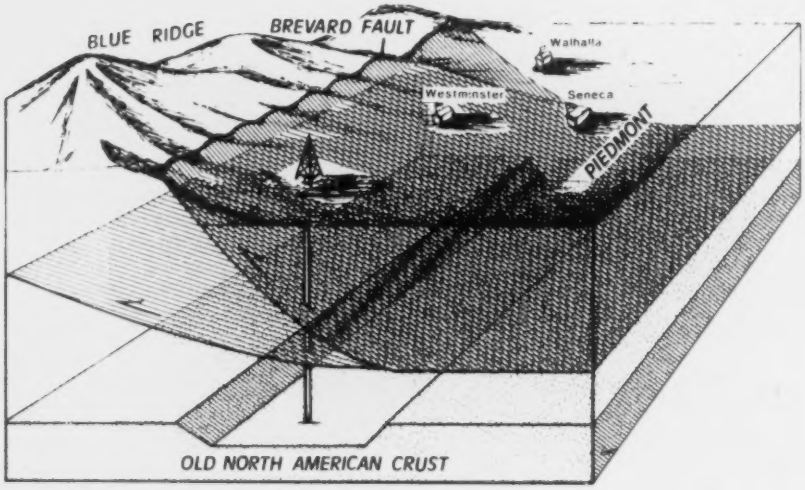
SUMMARY

We strongly support the establishment of a Continental Scientific Drilling Program in the United States. This program will over the next several decades enable scientists to better understand processes related to the evolution of continental crust, development of ultradeep drilling and coring technology, and produce useful information for applications to earthquake hazard research and hydrocarbon accumulations.

The National Academy of Sciences-endorsed ADCOH Project will address several important problems in crustal evolution and the processes of formation of mountain chains. It will also constitute a section through several types of crustal structures, permit measurment of stresses at mid-crustal depths, result in the development of ultradeep coring technology, and serve as a long-term observatory for crustal studies.

THE APPALACHIAN ULTRADEEP CORE HOLE (ADCOH) PROJECT

A PRIMER



Prepared By

Robert D. Hatcher, Jr.

Steven H. Edelman

and

Richard T. Williams

THE APPALACHIAN ULTRADEEP CORE HOLE (ADCOH) PROJECT

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Sponsored
APPALACHIAN ULTRADEEP CORE HOLE PROJECT
SITE SELECTION AND INVESTIGATION
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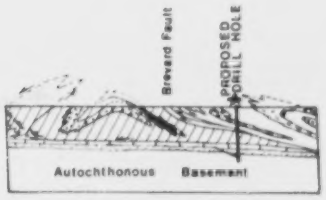


INTRODUCTION

The primary function of science is to push back the frontiers of knowledge. Most are attracted to the sciences by the lure of discovery of new concepts, the excitement of exploring the unknown, to gather data which lays the foundations for new ideas, to formulate these ideas, and prove old theories and hypotheses wrong. Whether the discovery is made by a mathematician with a pencil, a chemist in a modern laboratory, an astronomer with a radiotelescope, or a geologist using either a hand lens, compass and rock hammer, or an electron microscope and a complex computer, the excitement is the same.

Another aspect of science is its humbling effect upon its practitioners. The more we learn, the more we realize what we do not know. Thomas Huxley commented in 1887 about scientists:

> *We stand on an islet in the midst of an illimitable ocean of inexplicability. Our business in every generation is to reclaim a little more land.*

Our goal here is to extend the frontiers of knowledge of the earth's crust to a depth never before achieved in the western world. We propose to drill and core a more than six mile (33,000 feet, 10 km) deep scientific hole in the southern Appalachians in northwestern South Carolina or nearby northeastern Georgia. "Coring" the hole means that intact cylinders of drilled rock will be brought to the surface for examination and study.

This project is called the Appalachian Deep Core Hole (ADCOH) and has the primary goal of determining if a large inactive, horizontal fault (the Blue Ridge-Piedmont thrust), underlies a major part of the Appalachians (Fig. 1). This fault is thought to have moved a huge mass of rocks more than a hundred fifty miles (250 km) westward over the ancient edge of North America about 270 million years ago.

Drilling in the oceans for purely scientific purposes during the past 15 years has resulted in tremendous gains in our knowledge of the sea floor and its resources. A very deep hole into an ancient mountain chain will provide new information about the way mountain chains and even the continental crust are formed as well as provide spinoffs in the study of earthquakes, drilling technology, and mineral/hydrocarbon resources technology.

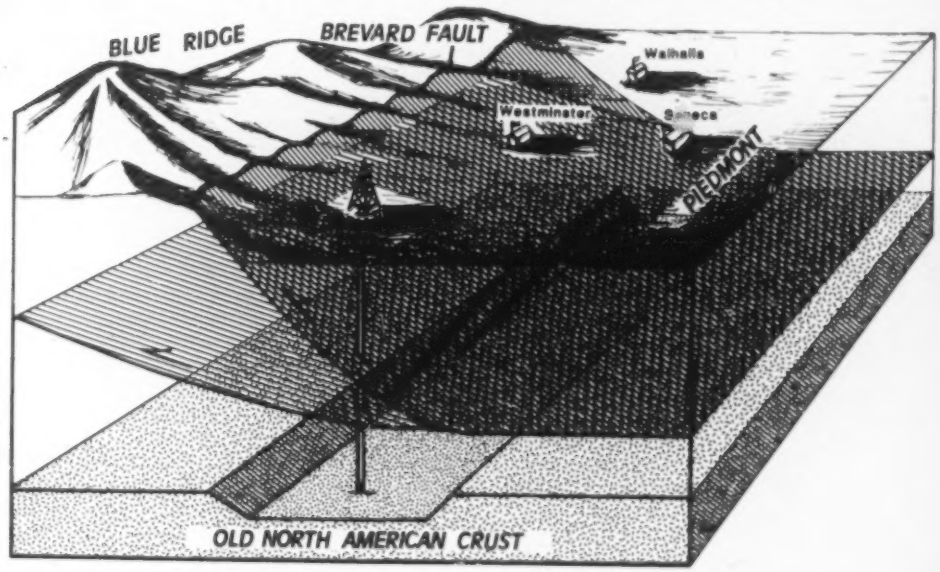


Figure 1. 3-d block diagram showing the major structures in the vicinity of the proposed Appalachian Deep Core Hole.

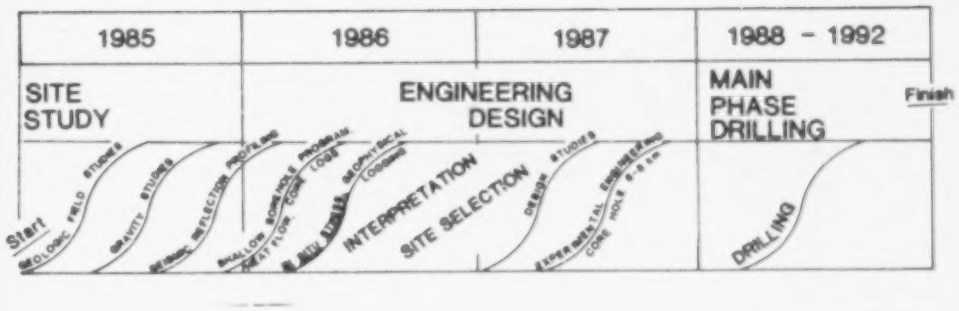


Figure 2. Time plan for activities

The ADCOH project will be conducted in four overlapping phases: Site selection, engineering design, main phase core drilling, and a post-drilling phase of additional scientific study (Fig. 2). The site selection phase began in early 1985 to locate a site to drill the deep hole.

The site selection process does not involve looking at farmland, streams and other features related to the present-day land surface. Rather, it involves the study of the earth's crust in the general vicinity (more than 2000 square miles) of the 220 square mile area where we think the site should ultimately be located. Surface geologic studies, seismic reflection profiling, measurements of gravity, heatflow, and present-day stress are being made using some of the most sophisticated equipment and techniques available in the world today to help us understand more about the structure the earth's crust in this area. The techniques being used will allow the most accurate images to be made of the crust of this part of North America without actually drilling the ultradeep hole.

The engineering design phase should begin before the end of the site study. ADCOH is planned so as to utilize existing drilling technology, but engineering design is needed to select and join together those components of existing technology needed to meet the specific problems anticipated in core drilling this particular hole. One of the major goals of the site study is to help define conditions and problems which will be encountered in drilling the deep hole. Also, to assist in design of ADCOH the engineering group proposes to drill and core a relatively shallow hole (15 to 20,000 feet) to gather data about drilling conditions in the deep hole.

The main drilling phase for the Appalachian Deep Core Hole will begin after both preliminary phases are complete and funding has been approved for this part of the project. At present, $2 million have been provided by the National Science Foundation for the site study. The engineering design and shallow core hole could cost as much as $10 million, while the deep core hole is estimated to cost up to $60 million. Compared to costs of other large research projects in physics and astronomy in the sciences and in engineering, medicine and other applied disciplines, this high cost is still relatively small.

ADCOH is expected to provide a number of long term benefits for the earth sciences community in addition to the immediate benefits derived from studies of the core and measurements made in the hole. Long term measurement of variations in stress, heat flow, magnetism and other properties deep within the crust should provide information not available here-to-fore. Considerable interest in ADCOH already exists among geologists, geophysicists, and geochemists throughout the United States. A West German consortium plans to drill a 15 km (49,000 ft) deep hole in the next several years. Greater international interest in this project will develop as it becomes better known. Because of the intense study this ADCOH site area has received already, and the amount of useful scientific data being produced here, we would like to declare this area an International Laboratory for Geologic and Geophysical Studies. Existing data, together with that from ADCOH, should provide a springboard for additional studies during the next several decades.

MOUNTAIN CHAINS

Most of us think of mountains as regions that provide winter and summer vacation spots, curving roads, waterfalls, and other features that are different from the usual flat to hilly areas where most of us live.

We were taught in geography that the present mountain chains may be classed as young or old based upon how rugged or worn down they are. The Alps, Rockies, and Himalayas are all thought of as young, rugged mountains, while the Appalachians are old and worn down. But when do mountains stop being mountains and become hills?

Geologists and geophysicists think of mountains as vestiges of crustal unrest where continents collided millions of years ago, or where earthquakes and volcanoes occur today and mountains are presently being built.We think the continents grew to their present sizes and shapes through eons of time by the addition of mountain chains around their margins. It is by this process that the continents of North and South America, Africa, Eurasia, and Australia were built. We also know today that most of the earth's mineral wealth form as deposits during the process of mountain building. Copper, tin, molybdenum, gold, silver and most other metals of wealth and technology were deposited as part of the same processes that built mountain chains.

The mountains of the U.S. are the Rockies, Sierra Nevada, Cascades and others making up the western Cordillera, the Appalachians and Adirondacks in the East, and the Ouachitas of Arkansas and Oklahoma. In addition, the eroded roots of very ancient mountains are present in Wisconsin and Minnesota, where only hills and farmland exist today. We can also drill less than a mile beneath the farmland of Kansas, Iowa or Ohio and encounter the roots of other more ancient mountain chains. All of these provide clues about the history of development of the earth's crust and the evolution of the North American continent.

The Appalachians have served as the cradle for many of the fundamental concepts of mountain building because of their accessibility and the abundant exposure of rocks within them. Actually, the region of the Appalachians, the geologic mountain chain, encompasses a much larger area than the hills and low mountains of today's Blue Ridge or the Cumberland and Allegheny Mountains. Today we know that the Appalachians contain the classic anatomy of many other mountain chains (Fig. 3). They were built on the ancient North American continental margin, not unlike that of the East Coast today, and experienced a history of faulting, volcanic activity, and related processes that are very similar to those which we can see occurring today in active volcanic chains in the western Pacific Ocean, in the Andes, and Himalayas.

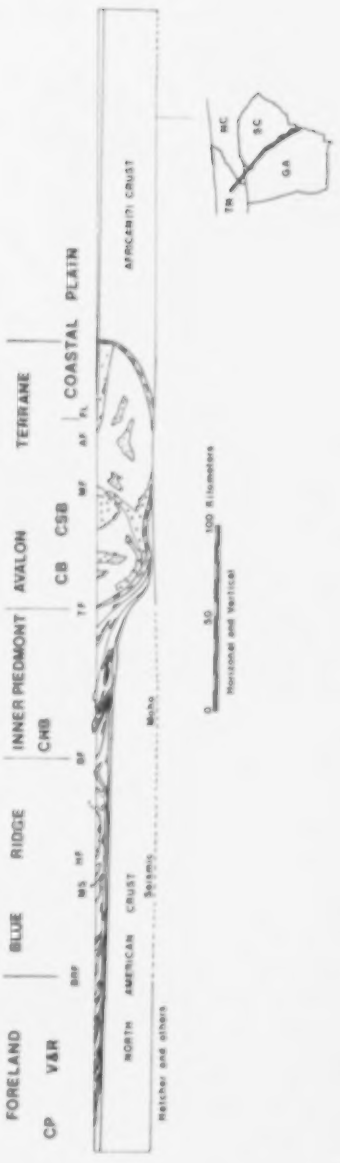


Figure 3A. Appalachian cross-section.

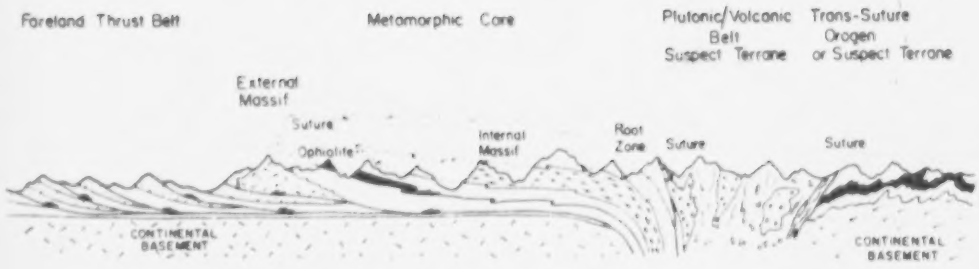


Figure 3. B. Ideal mountain chain

THE BUILDING OF THE APPALACHIANS

Many people are aware today that the theories of plate tectonics and continental drift predict that all the continents were once consolidated and formed a single huge continent called Pangaea. Subsequent rifting of Europe and Africa away from North and South America formed the present day Atlantic Ocean, which is still spreading the continents a little farther apart each day. The continents began drifting toward their present positions about 200 million years ago. We must therefore look back much farther in time, before Pangaea, when the continents were distributed around the world in a very different fashion from the present world geography.

In order to comprehend how the kinds of faulting and volcanic activity we see today in other parts of the world operated in the distant past to form the Appalachians, we must go back 500 million years to a time when the beaches and mudflats along the eastern shore of North America were positioned around Knoxville, Tennessee (Fig. 4). The land east of Knoxville - the Great Smoky Mountains - did not yet exist. It was at this time, when a map of the world would contain continents and islands that we would not recognize, before any life forms crawled out of the sea and onto the land, that beach sands, lagoonal muds, and coral reefs were deposited along the ancient North American shore and lithified to form the sedimentary rocks that are now seen in the mountains around Knoxville. If we could stand on this ancient shore and gaze out over that ancient sea, it would not be so different from standing today on Cape Hatteras or Myrtle Beach and looking east to the Atlantic horizon, except for the lack of vegetation on shore, since land plants had not yet evolved.

About 480 million years ago, this ancient ocean began to close prior to the formation of Pangaea. For two hundred million years, this once serene shore became the site of volcanic eruptions and earthquakes. It is the details of this time interval that are at the center of today's geologic research in the Appalachians. Volcanic mountain chains, some built at the continent's edge like modern Mount St. Helens, others in the ocean like modern Hawaii, were moved toward and over the continent along huge earthquake faults that acted like conveyors. Hundreds of small and large quakes, each moving a fault perhaps twenty feet (6 m) or less every hundred or so years, moved the faults hundreds of miles over millions of years of time.

By about 270 million years ago, the ancient ocean had closed completely. The African continental margin collided with the huge mass of faulted volcanic and sedimentary rocks at the edge of North America. The collision forced this huge mass of rocks at least another 150 miles (250 km) westward over parts of the continent farther inland. The rock mass moved along a large fault surface, the Blue Ridge-Piedmont thrust fault mentioned earlier. The towering Appalachian mountain chain was thus built, similar to the present Himalayan Mountains. (The Himalayas are the result of a collision between India, previously an island-continent like Australia, and southern Asia). This Appalachian collision marked the formation of Pangaea, the single supercontinent, which was to subsequently rift apart again about 200 million years ago to form the modern Atlantic Ocean.

The Appalachian Mountains have since been worn down by erosion, so when we look at rocks in outcrops we can see in their minerals and structures hints of the ancient volcanic eruptions and faulting, and with reflection seismology we can "see" what we think is the nearly horizontal Blue Ridge-Piedmont thrust along which most of the Appalachians were shoved westward. ADCOH will, when completed, give geologists a six mile (10 km) long cylinder of rock taken vertically through the Appalachians. The rock types (for example, volcanic or sedimentary) and structures (for example, faults and folds) observed along this cylinder of rock will rigorously test and doubtlessly modify and refine the scenario of con-

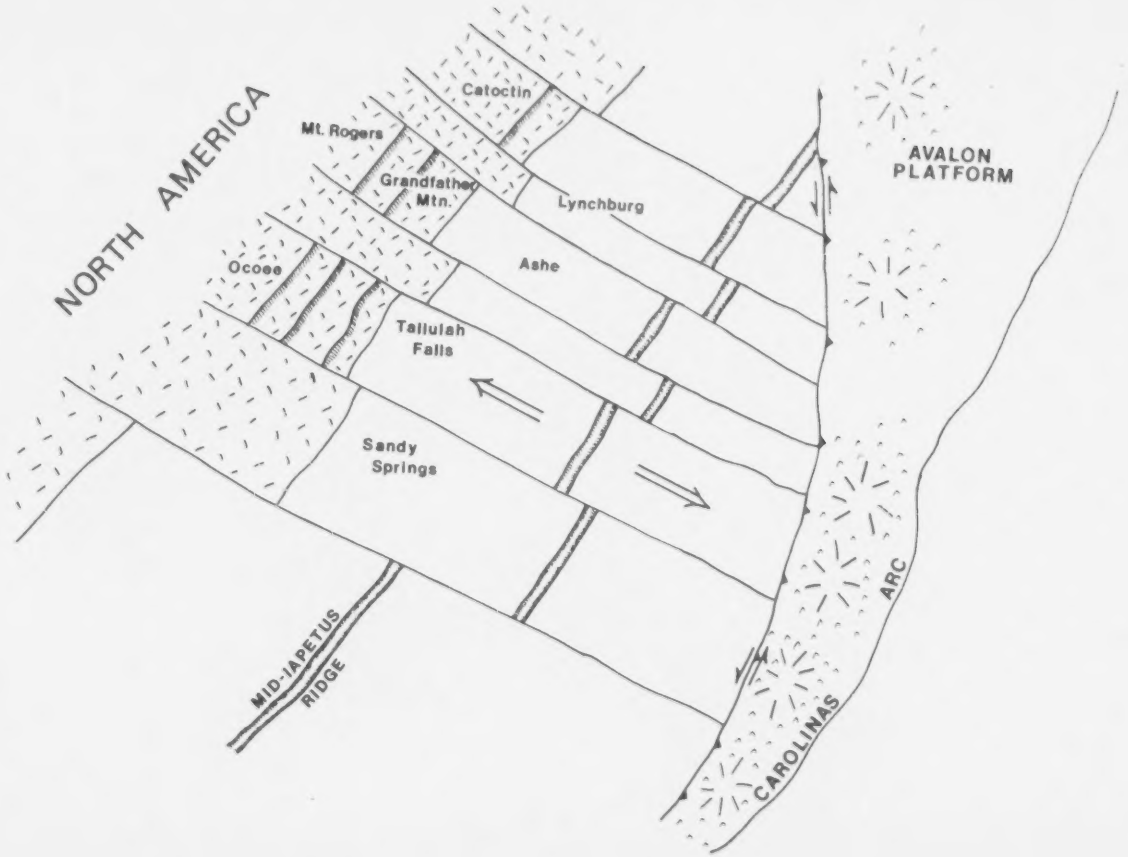


Figure 4. Edge of North American Continent approximately 500 million years ago showing the North American crust (cross-hatching) and the way the continental margin may have looked at this time, the ocean floor, and the Avalon-Carolinas volcanic arc, all of which were accreted to North America later. Ocoee, Mt. Rogers, Tallulah Falls, and others of rock units deposited before 500 million years ago.

tinental drift and collision outlined above. Because of its similarity to other mountain chains, the new insights gained into the origin of the Appalachian Mountains provided by ADCOH will have implications for the fundamental mountain building processes that operated throughout Earth's history to form the continent.

CRUSTAL STUDIES AND DRILLING

Most studies of the earth's crust are limited by the exposures of crustal rocks provided by nature: stream cuts, mountainsides and coastal exposures. At most these reveal one to two miles of vertical rock to observe at one place. Geologists can piece together segments of exposures from different parts of the same area and many times project these pieces to considerable depths to gain a three dimensional picture of the crust. Still, we are very limited in our attempts to understand and directly observe large portions of the earth's crust since it averages more than 20 miles (35 km) thick and in a few areas attains thicknesses of as much as 50 miles (80 km) in the continents. Indirect methods of observation, such as reflection seismology, provide us with only an approximate image of the structure of the crust. Other indirect methods are available to provide different kinds of data and therefore improve our knowledge, but they still provide an incomplete picture of the deep structure and nature of the continents. The ultimate key to understanding the great depths of the continents is through direct sampling of crustal materials at depth through core drilling.

Drilling provides a direct look into the third dimension in an otherwise largely two dimensionally accessible crust. The essential nature of drilling for scientific purposes has been utilized for several decades in the oceans. Industrial exploration for hydrocarbons and minerals has for almost a century depended upon samples obtained from drilling for the ultimate test for the existence of hydrocarbons or valuable metals. It is a logical step to systematically investigate the structure of continents using this as a scientific tool.

There are a number of problems in the United States which could usefully be addressed by drilling a deep core hole. A hole started in some of the very old crust exposed in Minnesota, or the Adirondack Mountains and drilled to considerable depths, would provide exciting and useful information about the nature of the deeper continental crust. This in turn will help us better understand both the way deposits of valuable minerals and hydrocarbons in mountain chains form, and how we can more easily find them.

The ultradeep hole being completed by the Russians in the Kola Peninsula of northwestern Russia addresses this problem of drilling a very deep hole into very old crust. The study which we propose involves drilling into crustal rocks which are not as old as these areas, to address a different problem of the formation of continental crust and the process of mountain building.

WHY DRILL?

Various kinds of measurements which can be made on the surface and the subsurface imaging techniques which we have available to us today, such as seismic reflection profiling, enable us to gain better knowledge about what is in the crust below the surface. However, in order to calibrate many of these techniques and to help us understand exactly how to interpret the images requires ultimately that a hole be drilled and samples recovered. Keeping in mind that the cost of drilling a very deep hole is very great, there must be a high probability of success in undertaking such a project. Consequently, the selection of a place to drill such a deep hole must be made carefully. There should be intermediate depth goals present to add to the potential gains from the drilling and completion of a hole of this kind.

THE HYPOTHESIS - WHY DRILL AND CORE A HOLE HERE?

The problem of drilling and coring an ultradeep scientific hole in the Appalachians arises from the hypothesis that a very large horizontal fault which carried a huge slab of crust westward into North America underlies a major portion of the central and southern Appalachians at depths ranging from 3 to 9 miles (5 to 15 km) (Fig. 3A). This hypothesis is derived partly from surface geologic studies conducted in the 1960's and early 1970's as well as from geophysical data for this region. These data include magnetic, gravity and seismic reflection profiling, which became available in the mid- to late 1970's. The existence of a large fault beneath a major portion of the Appalachian Mountains has implications that relate to the origin of mountain chains, as well as to the formation and evolution of continental crust. Similar structures exist in other mountain chains, such as the Caledonides of Britain and Scandinavia, and the eastern Alps of Switzerland and Austria. These structures, called crystalline thrust sheets, must have involved huge amounts of energy and would have taken several millions of years to move into their present positions. We think that the process of generation and emplacement of structures like this largely involves the collision of two continents. Yet structures of this type are also known in mountain chains such as the Cordillera in western Canada where continental collision has not occurred. So our objective in drilling a

very deep hole in the Appalachians is not only to test the hypothesis of the existence of a very large thrust sheet, the Blue Ridge-Piedmont thrust sheet, but also to study the origin of all structures of this kind. Intermediate goals include the investigation of a number of questions related to the internal structure of the large sheet through the vehicle of the ultradeep drill hole.

An ultradeep drill hole in the southern Appalachians would be located where the large Blue Ridge-Piedmont thrust sheet has a maximum width and its existence at depth could be tested (Fig. 5). It would be drilled far enough to the east so that its depth would be at about the maximum accessible by present technology.

The Appalachian site is also in a thermally benign area. We anticipate that temperatures at the bottom of the hole would not exceed 150 to 180°C (356°F). This would allow for study of a number of different processes including stress in the earth, possibly seismic monitoring, magnetic studies and other experiments which at high temperatures would be impossible because of the lack of stability of modern plastics and thermally sensitive instruments. The ADCOH project would therefore provide an opportunity for study of stress at mid-crustal depths never studied before in the North American continent at depths where earthquakes are generated.

SITE SELECTION FOR ADCOH

The selection of a site to drill an ultradeep core hole must be made very carefully not only because of the potential investment of both time and money but also to maximize the kinds and numbers of short and long term experiments which could be conducted in the hole. Therefore, we have formulated several criteria which are being employed in site and problem selection. The primary criterion must be that the nature of the problem to be addressed involves a fundamental concept in the earth sciences. More regional and local problems would also be addressed where appropriate. These problems involve a number of different disciplines within geological science, including tectonics, structural geology, stratigraphy, petrology, geophysics, geochemistry, seismology and others. There should also be intermediate depth objectives which could be met by drilling a very deep hole. These objectives must also be fundamental and of a high order of importance. They should exist because of the need to make significant gains if the deeper primary objective of the hole is lost. One intermediate depth goal is a major fault zone, the Brevard fault, which can be intersected at a depth of 4 to 5 km and surfaces not very far away. In addition, there are rocks exposed west of the Brevard fault zone which should project into the deep hole at a depth of 18 to 20,000 feet (6 to 7 km). Recovery of these rocks at considerable depths would permit comparison of the ancient pressure-temperature conditions that existed in these rocks (determined from the minerals) with pressure-temperature conditions determined from rocks accessible at the surface. These studies would enable us to gain a greater knowledge of the nature of the changes in temperature and pressure which take place in the crust when a mountain chain is being formed.

Another criterion of paramount importance in the siting and drilling of an ultradeep hole is that the target be of sufficient size and shape that the drill will intersect it. If the target at 7 km were so small that the likelihood of encountering it with the drill is not good, there is no point in undertaking the problem. The Appalachian target (the Blue Ridge-Piedmont thrust) is a large horizontal fault surface which, if it exists beneath the drill site, has a shape that will be encountered by the drill. Most importantly, if the fault is not encountered, the primary hypothesis we are testing would be disproved.

The southern Appalachian site area is probably the best site in the U.S. to test the hypothesis of the existence of large horizontal crystalline thrust faults at great depth (Figs. 3A, 5). This site represents a place as far as possible from the leading edge of the thrust sheet at its greatest width and still be at a depth where the target can be reached with existing technology. The Blue Ridge-Piedmont thrust sheet represents the largest structure of its kind in the Appalachians. It probably is the largest in the U.S., since there is no thrust sheet of crystalline rocks which has a greater extent or known horizontal displacement in the western U.S. mountains. Also, the depth of erosion of the Appalachians enables drilling to reach the critical depth to test the hypothesis, whereas the technology does not presently exist to drill to the critical depths necessary in the less deeply eroded mountain chains.

There are structures in Scandinavia and the Alps which are similar to the Appalachian thrust sheet. Much would be learned by drilling a deep hole through one of these thrust sheets. The Scandinavian Caledonides contain structures which may have a total displacement of 1000 km.

Unlike the Scandinavian and other large sheets of this kind, the Blue Ridge-Piedmont thrust sheet is intact. It has not been dismembered either tectonically by later faulting or cut by erosion, so it is a large continuous sheet and provides an excellent place to test this hypothesis.

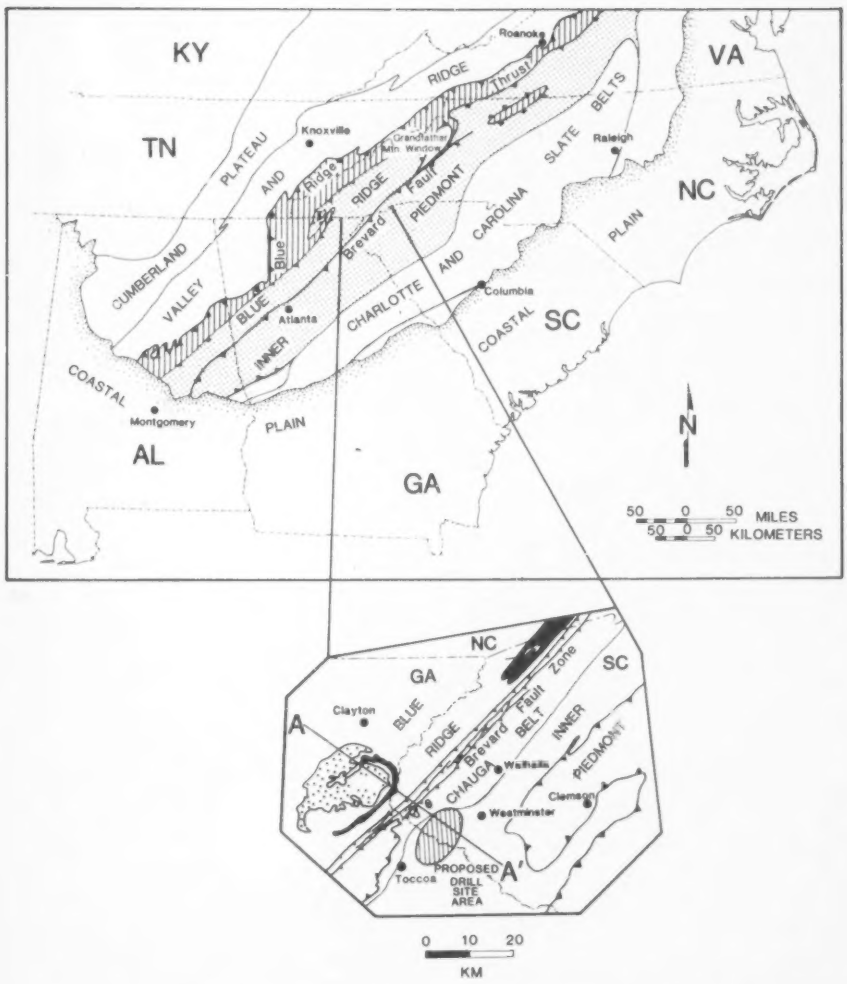


Figure 5. Map showing the major subdivision of the southern Appalachians and the location of the proposed drill site area opposite the maximum width of the thrust sheet. Inset shows greater detail near the proposed site. Black in the inset represents billion year old North American crust; the stippled area south of Clayton, Georgia, is part of the Tallulah Falls dome. A-A' is part of the cross-section in Figure 3A.

SITE SELECTION STUDY

A grant for $2 million was awarded in 1985 by the National Science Foundation to a five university consortium for selection of a site in the southern Appalachians for ADCOH. The University of South Carolina is the lead institution and directs the project. Geologists and geophysicists here are also involved in conducting the primary surface geologic and gravity studies as well as assisting in interpretation of other data gathered by geophysicists at other cooperating universities. Geophysicists from Virginia Polytechnic Institute, Princeton University, and Lamont-Doherty Observatory of Columbia University are processing and helping interpret seismic reflection data (Fig. 6). Geophysicists at Stanford University and Lamont-Doherty are involved in measurements of *in situ* stress and geophysical logging studies of the shallow boreholes which have been drilled (Fig. 7).

The present site study is a two year investigation with goals of primary data collection during the first year, and interpretation of data and ultimate site selection during the second year (1986). To date, some excellent seismic reflection data have been gathered over a distance of some 115 miles (200 km) in the study area in the Piedmont and Blue Ridge. The results so far indicate that the large thrust fault target may not be as deep as previously suggested using other older seismic reflection data. The new data indicate the principal target thrust fault may exist at a depth of 7 to 8 kilometers (22,000 to 25,000 feet) in the site area just southeast of the Brevard fault zone. If so, the cost of drilling and coring the hole to a shallower depth to test the hypothesis will be considerably less. However, the ultimate goal should be to penetrate the entire section of old sedimentary rocks and drill into the untransported North American crust beneath the Blue Ridge-Piedmont thrust.

ENGINEERING DESIGN OF ADCOH

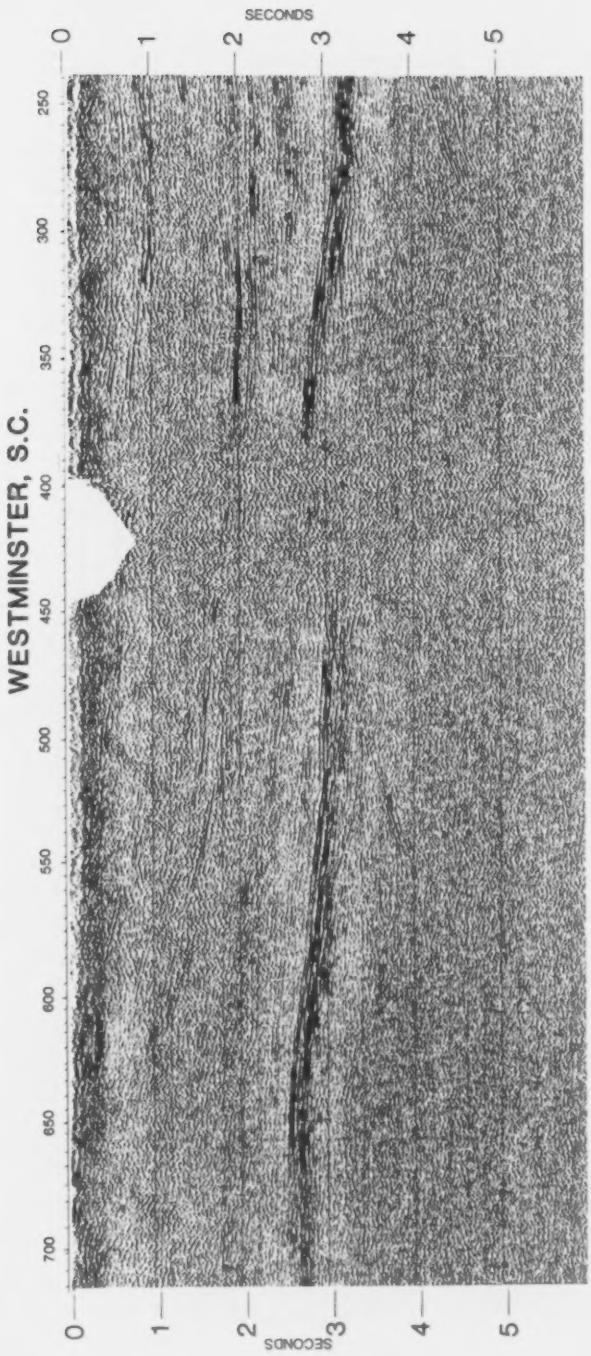
The design of the ultradeep core hole proposed to test the existence of the Blue Ridge-Piedmont crystalline thrust sheet requires great coordination and planning before the drilling can begin. However, there are several advantages to drilling into very old crystalline rocks rather than active fault zones, volcanic regions or even sedimentary basins, where conditions may make drilling more difficult, or even cause the hole to be lost. These include very high stresses and fractured rocks which could cause the hole to be caved and blocked. Exceptionally high temperatures could inhibit drilling or prevent scientific measurements of many geochemical and geophysical properties within the hole because most instruments break down at higher temperatures. The presence of caustic fluids, which might occur in deep sedimentary basins, could damage the drilling tools and instruments used for making scientific measurements.

None of these factors are thought to be present in the ADCOH site area, which makes it a very desirable place in which to undertake a deep drilling project. The rocks here are also very hard, which only would wear out a large number of drill bits. However, they do not have significant directional properties, such as a strong "grain", so that drilling of much of the hole could be carried out with relative ease. The temperatures anticipated at the bottom of the hole at 30,000 feet should not exceed 180°C (356°F). It is also very unlikely that drilling would encounter caustic fluids which would damage the drilling equipment or instruments.

The amount of core needed may create an additional problem. On a routine basis coring has not been carried out at depth greater than 15,000 feet (5 km) in the western world. This is about 10,000 feet (3 km) less than the minimal depth that should be drilled to prove or disprove the hypothesis of large scale crystalline thrusting in this region. The use of diamond bits for coring from the top to the bottom of the hole would prove to be very expensive. Some other coring technology may therefore be required, or even developed, so that the hole could be cored for less expense.

The actual design of the hole must take place from the bottom to the top. The diameter of core to be retrieved at the bottom is the limiting factor which determines the size of the hole at the surface. Another important factor is the minimum size hole into which most instruments will fit for making geophysical, geochemical and other measurements. The optimum minimum hole diameter may be 8 to 10 inches. The smallest core which could be effectively utilized if rock is from a very deep hole might be 2 inches in diameter. Consequently, the hole could be smaller than 6 inches if core is the only thing desired.

If the goal were simply to drill a hole, a large oil company rig could be used. However, since it may be possible to drill and core the hole using a modified mining type "slim hole" technology, a large oil company rig may not be needed. A medium size petroleum industry drilling rig could be modified so it could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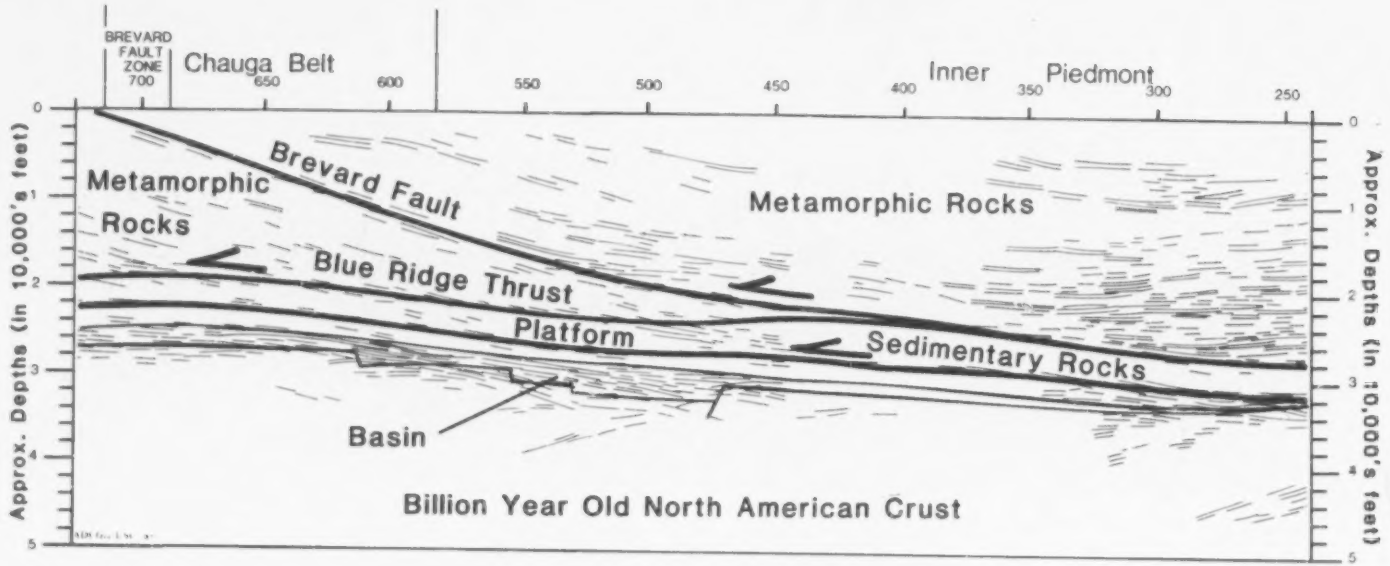

Figure 6. Part of Line 1 seismic reflection profile (location shown in Figure 7) with a tracing of reflectors and interpretation below. The major faults in the area appear to be clearly indicated in the profile and the location of the undeformed North American crust beneath can be seen beneath the platform sediments.

be utilized for coring at depths greater than 5 km (15,000 feet).

Most drilling engineers would prefer to employ a strategy of drilling a preliminary hole to the maximum capability of the present-day coring technology (5 to 7 km). The knowledge gained from drilling the shallow to intermediate depth hole would be used to rapidly drill a larger hole using a larger rig and not coring to the depth of the earlier core hole. Then once the earlier limit is reached, begin coring again. Others believe that the best technique is to go ahead and core the ultradeep hole from start to finish at the same site, perhaps reaming the hole several times at 10,000 foot intervals and repeat the coring procedure in the next interval.

No major technological breakthroughs are required in order to complete the ADCOH ten kilometer core hole. Modification of existing coring technology coupled with careful mechanical design of the hole and equipment are necessary. Also, it is important that engineering studies of the hole begin as soon as is practicable. Modification of existing technology for coring at depths greater than 15,000 feet will probably be accomplished through the use of some form of a "downhole motor". This would involve drilling and coring without the necessity of turning the entire drill string from the drill rig to the bottom of the hole. At depths greater than 10,000 feet, this involves a huge expenditure of energy and requires materials of very high strength to prevent the drill pipe from being twisted off in the hole. The deep hole in the Soviet Union has been drilled and cored using a downhole turbine motor. This particular system is driven by the pressure on the drilling fluid. Then the entire drill string can be designed to hold just the weight of the string. Lighter weight materials such as aluminum or titanium can possibly be used for the drill string if a downhole motor technology is used to core the ultradeep part of ADCOH.

DRILLING ADCOH

Once the final decision is made to drill ADCOH and the funding is made available, the site selected during the present study will be prepared for moving in the drill rig and beginning the drilling (Fig. 8). No more than 50 acres will be required for this entire drilling operation. A source of water will be required and an electric power substation will probably be needed. A service area will be constructed to hold drill pipe and other supplies for the drilling operation. A group of service buildings will be needed which could be converted for office space, places where preliminary scientific work will be done on core materials, and space for initial compilation and interpretation of data obtained during drilling. It is also anticipated that an observation area will be set up for the benefit of those who want to see the drilling operation as it proceeds.

The entire drilling and scientific data gathering process during drilling will probably take about three years. The hole will be started by drilling a somewhat larger diameter hole through the surficial weathered materials into solid rock. A portion of the weathered zone could be cored for scientists interested in studying near surface hydrologic and weathering processes. Once the drilling of this section is complete, a surface casing will be set to prevent influx of surface water. Core drilling should begin at a depth of between 1,000 and 2,000 feet (300 to 700 meters). As presently planned, coring will be a continuous process interrupted only to change bits, make downhole scientific measurements, or for repairs. An effort will be made to save costs by coordinating scientific measurements within the hole with times when the tools have to be out of the hole anyway to be repaired or new tools inserted.

Core from the hole (Fig. 9) will be examined immediately as it is brought to the surface, particularly as the hole gets deeper and drilling nears some of the major boundaries. It will be absolutely necessary to know during drilling where the bottom of the hole is geologically at every point from moderate depths to the principal target depth to help anticipate any problems that might occur at boundaries and to make certain the necessary scientific data are gathered at the correct depth.

Once drilling is close to the large horizontal thrust fault, the primary target, attempts will be made to determine if traces of hydrocarbons exist in the rocks immediately above the fault. This will provide indications of the possibility of large quantities of natural gas below the fault which could create problems in drilling as the fault is crossed. Presently, we think that the area beneath the large thrust fault should contain no hydrocarbons and that there should be a safe unpressured environment and benign region in which to drill from the surface to the projected bottom of the hole.

Core from ADCOH will provide many scientists with the opportunity to study the ancient high temperature-pressure conditions which affected rocks encountered in the hole that are presently at the surface in the Blue Ridge. This difference of several km in depth between today's surface and the point of sampling in ADCOH could prove very significant in studies of this kind and create an opportunity to learn more about the formation of these kinds of rocks and the processes that form them. In addition, once the hole reaches a depth of several kilometers, it will be possible for the first time in the western world to measure stresses at mid-crustal depths.

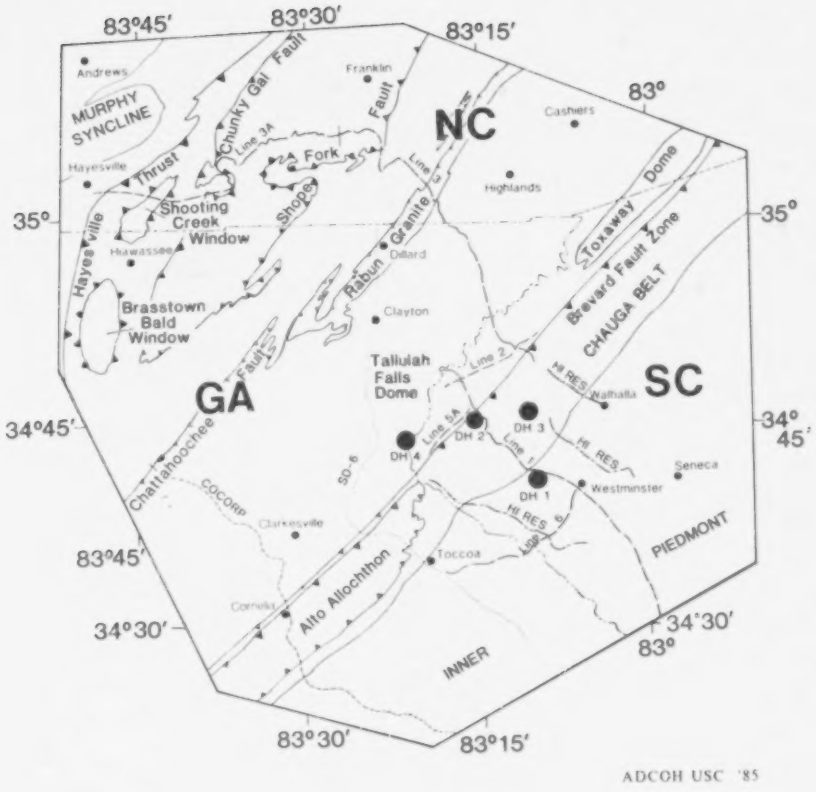

Figure 7. Map showing the locations of shallow boreholes, new seismic reflection lines (long dashed and dashed-dot lines), existing seismic reflection lines (short dashes and dotted lines) and the major structural features in the area.

Many other studies will be conducted both on the hole and on core. It is anticipated that during drilling and immediately thereafter as many as several hundred earth scientists will be involved in the study of the hole and core. Additional study of these materials will take place at least for the next decade following drilling.

WHAT IFS?

Several questions have been raised about the possible effects on the primary goals of the project if particular scenarios take place during drilling.

"WHAT WOULD HAPPEN IF THE DRILL DID NOT ENCOUNTER A MAJOR FAULT ZONE AT THE DEPTH ANTICIPATED?"

There are several possible answers: 1) the fault is at a greater depth, which is not presently indicated by any of our preliminary data studies; 2) the fault does not exist and the hypothesis would be disproved.

"WHAT IF A MAJOR FAULT IS ENCOUNTERED BUT THE SAME KINDS OF ROCKS ARE PRESENT ON BOTH SIDES? WOULD WE BE ABLE TO DETERMINE THAT WE HAD ACTUALLY ENCOUNTERED A FAULT?"

The kinds of structures, the intensity of their development, and the ages of the rocks should be distinctly different above and below the large horizontal fault. ADCOH site study data indicate that there will be significant difference in the rocks above and below the fault. The package of sedimentary rocks separating the similar thrust sheet and ancient North American crustal rocks beneath is much thicker than previously indicated. Therefore this problem should not arise.

Figure 8. Artist's concept of the appearance of the site once drilling is begun.

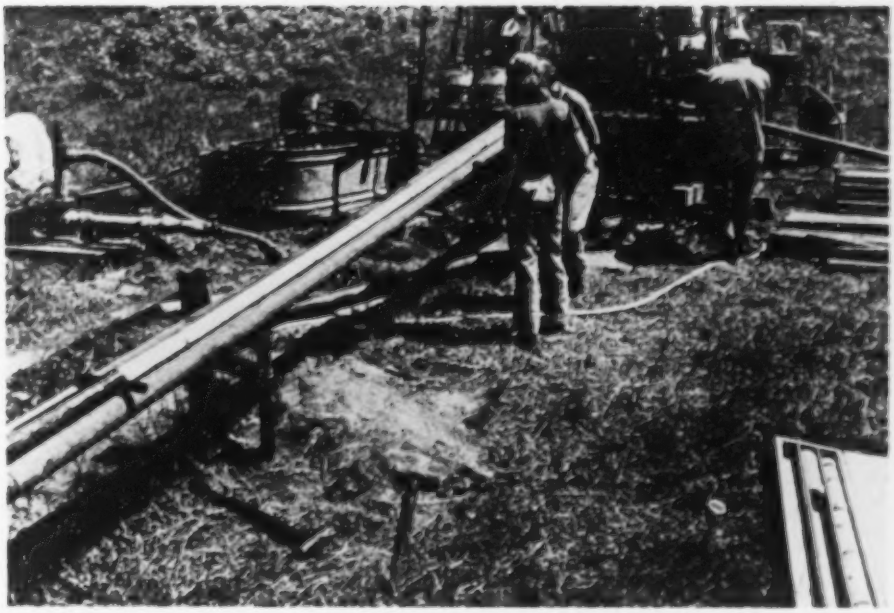

Figure 9. Geologists examining core from one of the shallow boreholes during the site location investigation.

"WHAT IF THE HOLE IS LOST AT A DEPTH OF 6 TO 7 KM (18,000 TO 22,000 FEET) AND WE ARE UNABLE TO COMPLETE IT?"

Because of the intermediate depth objectives built into this study, much will be gained from study of core and the hole at this depth. An intermediate depth hole would provide information about large fault zones, pressure-temperature conditions affecting these and surface rocks, other aspects of crustal evolution and the nature of stress in the present day crust. So despite the small likelihood that the hole would be lost above the target depth, a great deal would be derived from the hole.

LONG TERM USE OF THE SITE: THE CRUSTAL OBSERVATORY AND INTERNATIONAL LABORATORY

"ONCE CORING OF THE ULTRADEEP HOLE IS COMPLETED AND ALL THE INITIAL MEASUREMENTS MADE IN THE HOLE, SHOULD THE SITE BE ABANDONED AND RETURNED TO ITS ORIGINAL CONDITION, OR SHOULD IT CONTINUE TO SERVE SCIENTIFIC INTERESTS TO MAINTAIN AND KEEP IT OPEN AS LONG AS POSSIBLE?"

There are many experiments which can be carried out in the years following completion of ADCOH, provided it can be kept open.

Borehole seismometers or strain gauges can be installed to telemeter information to the surface about the nature of stresses, earthquakes and changes in the elastic properties of the earth in this area through time. The seismometer could also be used as a detector in experiments in which artificial (VIBROSEIS, explosive or other) sources of seismic energy could be used to provide more information about the crust and mantle.

A long term magnetometer study could be made to monitor changes in the earth's magnetic field through time. Various kinds of detectors for other kinds of radiation and influx of fluids into the hole could be installed. Additional surface geologic, geochemical and geophysical studies could be made in this area using the information from the deep hole as a focal point. Consequently, the long term use of this observatory and international laboratory for geologic, geochemical and geophysical studies is a natural consequence of the present series of investigations and coring of ADCOH. At the end of the present site study, this area may be the most intensively studied sizable part of any mountain chain in the world. There is no reason to expect an end to

these kinds of studies and drilling of ADCOH would result in a better understanding of not only the internal parts of an ancient mountain chain but the process of how continental crust forms.

Senator WARNER. The Chair wishes to express appreciation on behalf of the chairman of the full committee and other members of the Senate Energy Committee to those who have traveled long distances to join today in this very important hearing.

We will now start, in the absence of Senator Pressler, with panel 1, consisting of Dr. Dallas Peck, Director, U.S. Geological Survey, Department of the Interior; Dr. James F. Hays, Division Director for Earth Sciences, National Science Foundation; and Dr. Donald K. Stevens, Associate Director, Office of Basic Energy Science, Department of Energy.

I would ask the witnesses to come forward.

Dr. Peck, will you lead off?

STATEMENT OF DR. DALLAS L. PECK, DIRECTOR, U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

Dr. PECK. Yes, thank you, Senator.

Senator WARNER. I urge you to draw the microphone close, the reason being that there are many in the room who want to listen to your views.

Dr. PECK. Thank you, sir.

I am pleased to testify this morning before the subcommittee——

Senator WARNER. You are going to have to speak into it. Unfortunately, it is rather directional. So just take it as we politicians do and move it right along. It is all yours. [Laughter.]

Dr. PECK. I will try, Senator.

I am pleased to testify this morning before the subcommittee on S. 1026, the Continental Scientific Drilling and Exploration Act. The U.S. Geological Survey is an enthusiastic participant with the National Science Foundation and the Department of Energy in the Continental Scientific Drilling Program. I have been involved personally in the planning and interagency coordination for scientific drilling for over 15 years.

Except for section 4(5)(c) of the bill which requires funding estimates, we support passage of the bill and the continued oversight of the Congress in this important activity.

In my testimony, I hope to convey the broad array of natural resource and hazards problems and opportunities which such a program will address. We scientists have a sense of excitement in exploring the unknown through scientific drilling and a commitment to the scientific program that serves the needs of the Nation.

The USGS, through its own projects and through collaboration with the NSF and DOE, is currently participating in a vigorous effort to explore the continental crust through drilling. These efforts include a major project of drilling in the Salton Sea geothermal zone and plans for drilling this year near the San Andreas Fault at Cajon Pass in southern California. In addition, the Survey is cooperating with the NSF in providing core curator and storage facilities.

The composition, structure, origin, and history of the earth's continental crust have been the object of scientific and practical study for many years by earth scientists applying a great diversity of skills and techniques. Their methods of study started with direct mapping and observations of rocks exposed at the surface, rocks

which may once have been deeply buried, and have been extended using a variety of geophysical techniques.

For all of these efforts, our knowledge of the continental crust below about one-half mile remains very limited. The continental crust is complicated and fragmental, a residue of processes and forces acting on it since the history of the planet began. Our knowledge is limited to those restricted areas of economic interest where exploration for oil and for minerals has promoted drilling.

The scientific community has long realized the need for a major program to obtain information about the deeper structure of the continental crust. Both the NSF and the USGS started programs of deep seismic profiling in the 1970's in order to delineate the deeper structure and to identify targets for drilling.

Efforts to establish drilling programs were begun in the 1960's; and in the 1970's, the National Academy of Sciences sponsored several workshops to investigate the possible scope of a drilling program. Out of these workshops and their reports have come our present efforts to coordinate activities among the various Government agencies and to establish a national program for continental scientific drilling.

My colleagues here will speak of the importance of a drilling program for a better scientific understanding of the crust of the continent.

I strongly endorse these goals, because a better understanding can lead in the long range to a variety of benefits. However, I want to stress the more immediate practical benefits of continental scientific drilling.

An enhanced program to explore the continental crust by drilling would have a major impact on our understanding of the origin of mineral and energy resources and the processes by which they are concentrated within the crust as economically exploitable deposits. Such knowledge would enable us to make more accurate resource inventories and develop more successful exploration strategies.

Many important metals, including gold, silver, copper, cobalt, and tungsten are concentrated into mineral deposits deep below the surface by the underground circulation of very hot water, heated by the roots of volcanoes. Through time, these metal deposits are exposed at the surface by erosion. By comparing many ore deposits, geologists have reconstructed the events and processes leading to their formation.

However, our knowledge of such systems is very limited. At no single location have we been able to examine the full vertical dimension of a complete mineralizing system associated with a major ore deposit. The resource implications from gaining such knowledge are enormous because it could help us determine whether a shallow, weakly mineralized district is all there is, or whether it is only the upper tip of an economically important ore deposit at depth.

A program in continental scientic drilling also offers a unique opportunity to study the active geothermal systems that provide energy for electrical power generation. Deep drilling into a geothermal area would yield reliable field measurements to characterize the active in-place thermal system, revealing the pressure, temper-

ature, state-of-stress, fluid composition, and mineral and rock chemistry.

Our knowledge of oil and gas deposits is also limited by an incomplete understanding of the vertical dimension of the deposits and of the processes leading to their formation. Despite the great depths involved in drilling for oil and gas, such drilling rarely penetrates below reservoirs into the region of oil and gas generation and migration.

Deep drilling and related studies would yield valuable information on the organic chemistry of the hydrocarbons, of the temperatures that lead to the formation of oil and gas, and of the mechanisms of migration. A greater understanding of these factors could lead to improved exploration and an assessment of the Nation's oil and gas resources.

Continental scientific drilling could also make a major contribution toward reducing the hazards of earthquakes. The drilling program offers an unparalleled opportunity to understand the actual mechanisms that generate earthquakes which threaten millions of lives and billions of dollars of property, and which affect major military installations, as well as communication, transportation, and power generation and transmission systems.

The magnitudes of the stresses in and near major breaks in the crust, such as the San Andreas fault system in California, need to be measured in order to establish the boundary conditions for the movement of crustal blocks during an earthquake. We do not know whether the forces that drive this movement at depth overcome great or little frictional resistance.

However, boreholes within active fault zones to a depth of 3 miles or greater would provide the means of measuring the absolute state of stress at depths where earthquakes are presently occurring. Other critical parameters could be measured, such as the magnitude of fluid pressures in the rocks and their role in lubricating the sliding of crustal blocks, the temperature within the faults, and such physical properties as electrical transmission, fracture patterns, and the composition of fluids and gases in the fault zone.

Once completed, a drill hole offers the possibility of measuring changing conditions with time by establishing a deep seismic station. Using the noise-free environment at the bottom of the drill hole, advances could be made in predicting the process of earthquake initiation, propagation, and termination that would be fundamental to our understanding and would provide unique information that is unavailable to us in any other way.

An improved understanding of our continental crust by drilling would also yield information applicable to a variety of problems other than those related to natural hazards. These include the possible migration of toxic wastes injected as fluids into deeply buried sedimentary rocks and the possible migration of contaminated fluids from radioactive wastes stored at shallow depths.

In summary, the Continental Scientific Drilling Program provides a unique opportunity to make major scientific and technological advances in our understanding of the continental crust. These advances will result in data relevant to national needs, as well as for purely scientific purposes.

An established Continental Scientific Drilling Program would serve as the focus for coordinating efforts among all interested Government agencies, permit wide participation by Federal, State, and university scientists, be of great interest to industry, and would ultimately provide a national archive of information about the substructure of our continental crust. The information would be available to all agencies and citizens for use in solving critical problems, and for formulating new concepts about the deeper continental crust and its resources, which are now only at the edge of our focus and which represent the frontier of our knowledge.

Thank you, sir.

[The prepared statement of Dr. Peck follows:]

STATEMENT OF DALLAS L. PECK, DIRECTOR
U.S. GEOLOGICAL SURVEY
before the
SUBCOMMITTEE ON NATURAL RESOURCES DEVELOPMENT AND PRODUCTION
COMMITTEE ON ENERGY AND NATURAL RESOURCES
UNITED STATES SENATE

July 24, 1986

I am pleased to testify before the Subcommittee on S. 1026, the "Continental Scientific Drilling and Exploration Act".

The U.S. Geological Survey (USGS) is an enthusiastic participant with the National Science Foundation (NSF) and the Department of Energy (DOE) in the Continental Scientific Drilling Program. I have been involved personally in the planning and interagency coordination for scientific drilling for over 15 years. Provided that Sec 4 (5)(C) of the bill is deleted as discussed below, we generally support passage of the bill and the continued oversight of the Congress in this important activity. Section 4(5)(C), relating to the powers of the Interagency Coordinating Group, would constrain the ability of the President to allocate the budget as priorities suggest. We oppose this provision and recommend that it be deleted.

In my testimony, I hope to convey to you the broad array of scientific problems and challenges such a program will address. We scientists have a sense of excitement in exploring the unknown through scientific drilling and a commitment to a scientific program that serves the needs of our Nation. The USGS, through its own projects and through collaboration with the NSF and DOE, is currently participating in a vigorous effort to explore the continental crust through drilling. These efforts include a major project of drilling in

the Salton Sea geothermal zone and plans for drilling this year near the San Andreas fault, at Cajon Pass in Southern California. In addition, the USGS is cooperating with the NSF in providing core curator and storage facilities.

The composition, structure, origin, and history of the Earth's continental crust have been the object of scientific and practical study for many years by earth scientists applying a great diversity of skills and techniques. Their methods of study started with direct mapping and observations of rocks exposed at the surface, rocks which may once have been deeply buried. These methods have been extended using indirect surface studies such as measurements at the Earth's surface of the magnetic, electrical, seismic, and gravitational signals that come from deeply buried rocks. For all of these efforts, our knowledge of the continental crust below about 1/2 mile remains very limited. The continental crust is complicated and fragmental, and is a residue of processes and forces acting on it since the history of the planet began, and our knowledge is limited to those restricted areas where exploration for oil and for minerals has promoted drilling to recover economically valuable resources.

The scientific community has long realized a need for a major program to obtain information about the deeper structure of the continental crust. Both the NSF and the USGS started programs of deep seismic profiling in the 1970's, in order to delineate the deeper structure and to identify targets for drilling. Efforts to establish drilling programs were begun in the 1960's, and in the 1970's the National Academy of Sciences sponsored several workshops

to investigate the problems and the scope of a drilling program. Out of these workshops and their reports have come our present efforts to coordinate activities among the various government agencies and to establish a national program for continental scientific drilling.

My colleagues here will speak of the importance of a drilling program for a better scientific understanding of the crust of the continent. I strongly endorse these goals because a better scientific understanding of the crust can lead, in the long range, to a variety of benefits. However, I want to stress the more immediate, practical benefits of continental scientific drilling.

An enhanced program to explore the continental crust by drilling would have a major impact on our understanding of the origin of mineral and energy resources and the processes by which they are concentrated within the crust as economically exploitable deposits. Such knowledge would lead to the construction of mineral deposit models which would enable us to make more accurate resource inventories and develop more successful exploration strategies.

Many important metals, including gold, silver, copper, cobalt, tin, and tungsten are concentrated into mineral deposits deep below the surface by the underground circulation of very hot water, heated by the roots of volcanoes. Through time, these metal deposits are exposed at the Earth's surface by erosion. By comparison of many ore deposits, geologists have reconstructed the events and processes leading to their formation. However, our knowledge

of such systems is very limited because the overall size is much larger than those parts that are exposed at the surface or are accessible at current mining and exploration drilling depths. At no location have we been able to examine the full vertical dimension of a complete mineralizing system associated with a major ore deposit. The resource implications from gaining such knowledge are enormous because we do not know if a shallow, weakly mineralized district is all there is, or whether it is only the upper tip of an economically important ore deposit at depth.

A program in continental scientific drilling also offers a unique opportunity to study the active geothermal systems that provide energy for electrical power generation. Again, the study of active geothermal systems is restricted to near surface data, shallow drill hole investigations, and comparison with exposed fossil systems. Deep drilling into a geothermal area would yield reliable field measurements to characterize the active in-place thermal system, showing the pressure, temperature, state-of-stress, fluid composition, and mineral and rock chemistry.

Our knowledge of oil and gas deposits is also limited by an incomplete understanding of the vertical dimension of the deposits and of the processes leading to their formation. Despite the great depths involved in drilling for oil and gas--for example, there are many wells in Texas and Oklahoma that exceed 20,000 feet--drilling always stops near the depth where the oil or gas reservoir is reached. Below that zone is the region of oil and gas generation and migration, a region that is almost completely unstudied. So, a deep

drilling program would give invaluable information on the limits of gas generation and limits of the stability of such gases as methane, carbon dioxide and hydrogen sulfide. Deep drilling would facilitate studies of the organic chemistry of the hydrocarbons, of the temperatures that lead to the formation of oil and gas, and of the mechanisms of migration. A greater understanding of the origin of these critical resources would lead to improved exploration and assessment of the Nation's oil and gas resources.

Continental scientific drilling can also make major contributions toward reducing the hazards of earthquakes. Forces that are active deep in the continental crust have a profound and sometimes dramatic impact at the Earth's surface in the form of volcanic eruptions or great earthquakes. The drilling program offers an unparalleled opportunity to understand the actual mechanisms that generate earthquakes which threaten millions of lives and billions of dollars of property, and which affect major military installations as well as communication, transportation, and power generation, and transmission systems.

The magnitudes of the stresses in and near major breaks in the crust, such as the San Andreas fault system in California, need to be measured to establish the boundary conditions for the movement of crustal blocks during an earthquake. We do not know whether the forces that drive this movement at depth overcome great, or little, frictional resistance. However, boreholes to a depth of 3 miles or greater within active fault zones would provide the possibility of measuring the absolute state-of-stress at depths where earthquakes are presently occurring. Other critical parameters need to be

measured, such as the magnitude of fluid pressures in the rocks and their role in lubricating the sliding of crustal blocks, the temperature within the faults derived from the shearing of rocks, and such physical properties as electrical transmission, fracture patterns, and composition of the fluids and gases in the fault zone. Once completed, a drill hole offers the possibility of measuring changing conditions with time by establishing a deep seismic station. In a noise-free environment at the bottom of the drill hole, advances could be made in predicting the process of earthquake initiation, propagation, and termination that would be fundamental to our understanding, and would provide unique information that is unavailable to us in any other way.

An improved understanding of our continental crust by drilling would also yield information applicable to a variety of problems other than those related to natural hazards. These include the possible migration of toxic wastes injected as fluids into deeply buried sedimentary rocks and the possible migration of contaminated fluids from radioactive wastes stored at shallow depths.

In summary, a continental scientific drilling program provides a unique opportunity to make major scientific and technological advances in our understanding of the continental crust. These advances will result in data relevant to national needs as well as for purely scientific purposes. An established continental scientific drilling program would serve as a focus for coordinating efforts among all interested government agencies, permit wide

participation by Federal, State, and university scientists, be of great interest to industry, and would ultimately provide a national archive of information about the substructure of our continental crust. The information would be available to all agencies and citizens for use in solving critical problems and for formulating new concepts about the deeper continental crust and its resources, which are now only at the edge of our focus and which represent the frontier of our knowledge.

Senator WARNER. Thank you.

At this time, the Chair recognizes first my distinguished colleague from Nevada who has joined us this morning. Do you have an opening statement, Senator Hecht?

Senator HECHT. No. Thank you very much.

Senator WARNER. The committee will now recognize the distinguished Senator from South Dakota, Senator Pressler.

STATEMENT OF HON. LARRY PRESSLER, A U.S. SENATOR FROM THE STATE OF SOUTH DAKOTA

Senator PRESSLER. Thank you very much, Mr. Chairman.

First of all I want to thank you for holding this hearing, and I want to thank our witnesses. We have had a great deal of interest in this from our State, from the School of Mines.

But very briefly, I would ask unanimous consent to place my statement in the record, and I shall just summarize a few points from it.

Senator WARNER. Without objection.

Senator PRESSLER. Let me say that your staff has been most helpful in this endeavor.

Today this subcommittee is beginning an extremely important inquiry into an issue which I believe parallels in importance our efforts in the space program. Other witnesses this morning can illustrate much better than I of the benefits and importance of this program.

My purpose this morning is to provide your subcommittee with a bit of background on the legislative history behind the Continental Scientific Drilling Program and seek your support in getting this bill to the Senate floor as soon as is practicable.

Roughly 2 years ago Dr. Jim Papike came to see me in one of my South Dakota field offices, and I see him here today. His enthusiasm for this program quickly rubbed off on me as he explained the great potential behind continental scientific drilling. I just admit that my interest was peaked because of parochial concerns, but having been involved in the program for over 2 years now it is clear to me that this is a truly national program.

In the fall of 1984 I introduced a resolution setting forth the policy goals of CSDP, the Continental Scientific Drilling Program, and putting the Congress on record in support of its implementation. It was accepted as an amendment to the fiscal year 1985 continuing resolution and signed into law on October 12, 1984.

The following April I introduced S. 1026, the Continental Scientific Drilling and Exploration Act of 1985, which is being considered by the subcommittee today. As of yesterday, we had eight cosponsors—Senators Durenberger, Matsunaga, Moynihan, Heinz, Domenici, Nickles, Stevens, and Bentsen.

Before emphasizing what this legislation does, it is important to emphasize what it will not do. It will not add a single penny to the budget. I want to stress that point in an effort to encourage action on the measure this year. It is my hope that we can get this legislation enacted into law during this Congress.

Let me highlight just briefly what the bill does. In setting forth the purposes and findings, it highlights some of the most funda-

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mental benefits to be derived from the program. Section 4 contains the operative language. In essence it encourages the continuation of the cooperative effort that has been going on for many years between the Departments of Interior and Energy and the National Science Foundation.

The Interagency Coordinating Group referred to in the legislation has been in existence for roughly 3 years. Perhaps more importantly, section 4 directs the Interagency Coordinating Group to prepare and submit to Congress a plan of action for the implementation of CSDP. In essence, we are asking them to tell us how long it would take, how much it costs, and what benefits we can expect to gain from a Continental Scientific Drilling Program.

The bill is brief. Its language is self-explanatory. It would require no additional funding. The administration has been very supportive of the effort, and I hope the administration witnesses which follow can verify a continuation of that support.

Finally, I know of no opposition to this bill. So in conclusion, it would be my hope that after you have had a chance to review this legislation today, the committee will be in a position to vote on reporting the bill to the Senate in time for a floor vote and House action yet this year.

With that, Mr. Chairman, I will close my comments with respect to the legislation and take just a minute to introduce one of the witnesses to testify a little later this morning.

We in South Dakota were very fortunate to succeed in coaxing Dr. Jim Papike to the South Dakota School of Mines and Technology. We stole him from New York 4 years ago. Jim is a great asset to the State, and it has been my privilege to get to know him as a result of this program. He has been the motivating force behind this legislation, and I am pleased that he was able to join in the discussion this morning.

I have also noticed on the witness list and have been listening this morning to U.S. Geological Survey Director Dallas Peck who is on the panel preceding me. We have worked closely with Dr. Peck on a number of issues important to my State. He is a good friend and an articulate spokesman, so I feel comfortable in ending here and turning the table over to him and the other witnesses.

I would conclude by thanking you again, Mr. Chairman, for taking the time and particularly the efforts of many of your staff members and your assistants in holding this important hearing.

[The prepared statement of Senator Pressler follows:]

STATEMENT OF SENATOR LARRY PRESSLER
BEFORE THE SUBCOMMITTEE ON NATURAL RESOURCES DEVELOPMENT AND PRODUCTION OF THE COMMITTEE ON ENERGY AND NATURAL RESOURCES
HEARING REGARDING S.1026
JULY 24, 1986

I WOULD LIKE TO BEGIN THIS MORNING WITH A PERSONAL NOTE OF THANKS TO YOU, CHAIRMAN WARNER, FOR HOLDING THIS IMPORTANT HEARING TODAY. YOU AND YOUR STAFF HAVE BEEN MOST HELPFUL.

TODAY YOUR SUBCOMMITTEE IS BEGINNING AN EXTREMELY IMPORTANT INQUIRY INTO AN ISSUE WHICH I BELIEVE PARALLELS IN IMPORTANCE OUR EFFORTS IN THE SPACE PROGRAM. OTHER WITNESSES THIS MORNING CAN ILLUSTRATE MUCH BETTER THAN I THE BENEFITS AND IMPORTANCE OF THIS PROGRAM. MY PURPOSE THIS MORNING IS TO PROVIDE YOUR SUBCOMMITTEE WITH A BIT OF BACKGROUND ON THE LEGISLATIVE HISTORY BEHIND THE CONTINENTAL SCIENTIFIC DRILLING PROGRAM, AND SEEK YOUR SUPPORT IN GETTING THIS BILL TO THE SENATE FLOOR AS SOON AS PRACTICABLE.

ROUGHLY TWO YEARS AGO, DR. JIM PAPIKE CAME TO SEE ME IN ONE OF MY SOUTH DAKOTA FIELD OFFICES. HIS ENTHUSIASM FOR THIS PROGRAM QUICKLY RUBBED OFF ON ME AS HE EXPLAINED THE GREAT POTENTIAL BEHIND CONTINENTAL SCIENTIFIC DRILLING. I MUST ADMIT THAT MY INTEREST WAS PIQUED BECAUSE OF PAROCHIAL CONCERNS, BUT HAVING BEEN INVOLVED IN THE PROGRAM FOR OVER TWO YEARS NOW, IT IS CLEAR TO ME THAT THIS IS A TRULY NATIONAL PROGRAM.

IN THE FALL OF 1984 I INTRODUCED A RESOLUTION SETTING FORTH THE POLICY GOALS OF CSDP AND PUTTING THE CONGRESS ON RECORD IN SUPPORT OF ITS IMPLEMENTATION. IT WAS ACCEPTED AS AN AMENDMENT TO THE FY 85 CONTINUING RESOLUTION AND SIGNED INTO LAW ON OCTOBER 12, 1984.

THE FOLLOWING APRIL I INTRODUCED S. 1026, THE CONTINENTAL SCIENTIFIC DRILLING AND EXPLORATION ACT, WHICH IS BEING CONSIDERED BY THE SUBCOMMITTEE TODAY. AS OF YESTERDAY, WE HAVE EIGHT COSPONSORS: SENATORS DURENBERGER, MATSUNAGA, MOYNIHAN, HEINZ, DOMENICI, NICKLES, STEVENS AND BENTSEN.

BEFORE DISCUSSING WHAT THIS LEGISLATION DOES, IT IS IMPORTANT TO EMPHASIZE WHAT IT WILL NOT DO. IT WILL NOT ADD A SINGLE PENNY TO THE BUDGET. I WANT TO STRESS THAT POINT IN AN EFFORT TO ENCOURAGE ACTION ON THIS MEASURE THIS YEAR. IT IS MY HOPE THAT WE CAN GET THIS LEGISLATION ENACTED INTO LAW DURING THIS CONGRESS.

LET ME HIGHLIGHT JUST BRIEFLY WHAT THE BILL DOES. IN SETTING FORTH THE "PURPOSES" AND "FINDINGS," IT HIGHLIGHTS SOME OF THE MOST FUNDAMENTAL BENEFITS TO BE DERIVED FROM THE PROGRAM. SECTION 4 CONTAINS THE OPERATIVE LANGUAGE. IN ESSENCE, IT ENCOURAGES THE CONTINUATION OF THE COOPERATIVE EFFORT THAT HAS BEEN GOING ON FOR MANY YEARS BETWEEN THE DEPARTMENTS OF INTERIOR AND ENERGY AND THE NATIONAL SCIENCE FOUNDATION. THE INTERAGENCY COORDINATING GROUP REFERRED TO IN THE LEGISLATION HAS BEEN IN EXISTENCE FOR ROUGHLY THREE YEARS. PERHAPS MOST IMPORTANTLY, SECTION 4 DIRECTS THE INTERAGENCY COORDINATING GROUP TO PREPARE AND SUBMIT TO CONGRESS A PLAN OF ACTION FOR THE IMPLEMENTATION OF CSDP. IN ESSENCE, WE ARE ASKING THEM TO TELL US HOW LONG IT WOULD TAKE, HOW MUCH IT COSTS, AND WHAT BENEFITS WE CAN EXPECT TO GAIN FROM A CONTINENTAL SCIENTIFIC DRILLING PROGRAM.

THE BILL IS BRIEF. ITS LANGUAGE IS SELF EXPLANATORY. IT WOULD REQUIRE NO ADDITIONAL FUNDING. THE ADMINISTRATION HAS BEEN VERY SUPPORTIVE OF THE EFFORT, AND I HOPE THE ADMINISTRATION WITNESSES WHICH FOLLOW CAN VERIFY THE CONTINUANCE OF THAT SUPPORT.

FINALLY, I KNOW OF NO OPPOSITION TO THIS BILL.

SO IT WOULD BE MY HOPE THAT AFTER YOU HAVE HAD A CHANCE TO REVIEW THIS LEGISLATION TODAY, THE COMMITTEE WILL BE IN A POSITION TO VOTE ON REPORTING THE BILL TO THE SENATE IN TIME FOR A FLOOR VOTE AND HOUSE ACTION YET THIS YEAR.

WITH THAT, MR. CHAIRMAN, I WILL CLOSE MY COMMENTS WITH RESPECT TO THE LEGISLATION AND TAKE JUST A MINUTE TO INTRODUCE ONE OF THE WITNESSES TO TESTIFY A LITTLE LATER THIS MORNING. WE IN SOUTH DAKOTA WERE VERY FORTUNATE TO SUCCEED IN COAXING DR. JIM PAPIKE TO THE SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY. WE STOLE HIM FROM NEW YORK FOUR YEARS AGO. JIM IS A GREAT ASSET TO THE STATE, AND IT HAS BEEN MY PRIVILEGE TO GET TO KNOW HIM AS A RESULT OF THE PROGRAM. HE HAS BEEN THE MOTIVATING FORCE BEHIND THIS LEGISLATION, AND I AM PLEASED THAT HE WAS ABLE TO JOIN IN THE DISCUSSIONS THIS MORNING.

I ALSO NOTICED ON THE WITNESS LIST THIS MORNING THAT U.S. GEOLOGICAL SURVEY DIRECTOR DALLAS PECK WILL BE FOLLOWING ME. WE HAVE WORKED CLOSELY WITH DR. PECK ON A NUMBER OF ISSUES IMPORTANT TO MY STATE. HE IS A GOOD FRIEND AND AN ARTICULATE SPOKESMAN, SO I FEEL COMFORTABLE IN ENDING HERE AND TURNING THE TABLE OVER TO HIM AND THE OTHER WITNESSES.

THANK YOU AGAIN, MR. CHAIRMAN, FOR YOUR ASSISTANCE IN HOLDING THIS IMPORTANT HEARING.

Senator WARNER. Thank you, Senator.

Senator PRESSLER. Would Dr. Jim Papike please rise? He is the man who started this. We are very happy to see you here, and we have been hearing from Dallas Peck.

Senator WARNER. Thank you very much, Senator, for joining us this morning.

We will now hear from Dr. Hays.

STATEMENT OF DR. JAMES FRED HAYS, DIRECTOR, DIVISION OF EARTH SCIENCES, NATIONAL SCIENCE FOUNDATION

Dr. HAYS. Senator, with your permission I would like to summarize my written testimony.

Senator WARNER. Yes, I think that would be very helpful. We have a long list of witnesses today, and we want to hear and accord each a fair allocation of time. If you could hold your remarks to 5 minutes or less, the Chair and members of the committee would be appreciative.

Dr. HAYS. Thank you.

The National Science Foundation has been in the business of scientific drilling for a long time, but in the past most of that has been in the ocean basins. Out of the ocean drilling program and the deep-sea drilling program have resulted the confirmation of the theory of plate tectonics, information about the past climates, about the structure and evolution of the sea floor, and past movements of continents. It has been a very successful, and continues to be a very scientifically productive program.

The difficulty with that is that the continents are very different from the oceans. The ocean floor is constantly being recycled and renewed, and as a result none of it is much older than about 200 million years, and that is only a small fraction of the age of the Earth. The continents on the other hand are very old. There are parts of the continents that are as old as 4 billion years.

As Dr. Peck mentioned, they record a very long history of continental collisions, rifting, breakups, motions, the formation of sedimentary basins, many processes that are not only of great scientific interest but also, as he emphasized, of great practical interest. If we wish to study these, it is necessary for us to study the continents.

While for a long time there has been geological and geophysical study of the continents, most of it has been confined to the surface, or very shallow depths, and it is important more than ever now to explore the deeper parts of the continents and use all the tools available to do that.

So as a result, 2 years ago the Foundation began a new continental lithosphere program with the aim of providing the most modern and most powerful tools to study this unexplored part of the continents beneath our feet. Now among these tools, some of which I will mention later, drilling is one of the most important.

Now the petroleum industry and the mining industry have done a lot of drilling in the past, but the mining industry's drilling has been very shallow—normally a few hundred to a few thousand feet. The petroleum industry has drilled some very deep holes, but those

holes have been almost entirely in the sedimentary basins which are a very small fraction of the continental crust.

There are many scientific problems that are related to these older parts of the crust that record ancient movements. The Foundation is now supporting an organization called DOSECC, Deep Observation and Sampling of Earth's Continental Crust. This is a consortium of 33 universities that was organized specifically to plan and manage the Foundation's activities in continental scientific drilling.

Now you will probably hear more about this from other witnesses, so I will just mention that it was patterned after the organization that operates the ocean drilling program, and it plays essentially the same role for the National Science Foundation's drilling activities.

The Foundation also participates with the Department of Energy and the Geological Survey under the Interagency Accord on Continental Scientific Drilling. This accord ensures that there will be communication and coordination among these three agencies, and also makes it possible for all of the agencies to participate in the funding of research on holes that are drilled regardless of which agency primarily initiates the hole. There is an interagency coordinating group which meets very frequently, and the cooperation in my opinion among these agencies has been excellent.

Now the Continental Lithosphere Program also supports other geophysical tools aimed at deep continental exploration: Seismic reflection profiling, for example. This is a technique that was developed and much used by the oil companies in the shallow sedimentary basins. NSF funded a cocorp project at Cornell University that has shown that this same technique can be extended and used to study the entire thickness of the continental crust. A similar technique is being used by a group called CALCRUST looking at regional problems in Southern California.

We also support another consortium called IRIS, this one consisting of about 50 universities, that is engaged in developing seismograph array technology, digital seismographs that are operated as arrays that can be used to form three-dimensional images of parts of the crust using the same kinds of techniques that are used to make CAT scans of the human body, for example, tomographic techniques.

We also support activities that make use of the geodetic satellites that the Defense Department has been providing that will allow us to make measurements of distances on the surface of the Earth as accurate as a centimeter or so. This makes it possible to actually observe tectonic movements, observe the movements of plates, creep-along faults, swelling of volcanoes, and the like.

Now I would emphasize that all of these efforts together are needed. For example, you can do all the geophysics that you want, but you do not really know what is down there until you drill a hole. The geophysical data needs to be calibrated and the drill hole provides that calibration.

On the other hand, a drill hole is only a few inches wide, so that unless you use the geophysical techniques to extend and enhance the information that you get from the drill hole, you are not get-

ting the maximum information from it. So it is important that there be a balanced and coordinated program.

In summary, the National Science Foundation regards scientific drilling on the continents as an important component of its Continental Lithosphere Program, and as an appropriate complement to its Ocean Drilling Program.

I would be happy to answer any questions you might have.

[The prepared statement of Dr. Hays follows:]

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National
Science
Foundation

TESTIMONY OF

DR. JAMES FRED HAYS

DIRECTOR, DIVISION OF EARTH SCIENCES

NATIONAL SCIENCE FOUNDATION

BEFORE

SENATE ENERGY AND NATURAL RESOURCES COMMITTEE

SUBCOMMITTEE ON NATURAL RESOURCES DEVELOPMENT AND PRODUCTION

JULY 24, 1986

For the last twenty years the National Science Foundation has supported a program of drilling for scientific research on the floors of the world's oceans. Results of this drilling include convincing confirmation of the concepts of seafloor spreading and plate tectonics, evidence for a history of drastically changing climates, and many other new insights into the circulation of the oceans, the age and composition of the oceanic crust, and the volcanic processes that formed it. This program will continue to produce exciting scientific results.

The oceanic crust, however, records only the most recent 5% of the earth's history. To understand the other 95% we must explore the deeper parts of the continents using a variety of geological and geophysical tools that are now available. Parts of the continental crust are nearly 4 billion years old and record a long history of repeated rifting, drifting, and collision events. Many of the geologic processes that produce mineral and energy resources or present hazards to mankind can best be studied on land. Two years ago the Foundation began a new Continental Lithosphere Program designed to focus attention on the continents and to encourage the coordinated efforts that are necessary to make efficient use of expensive deep exploration techniques. Through this program the Foundation has supported increased use of seismic and other geophysical techniques aimed at probing deeper into the earth than we have been able to in the past. An important part of this program is the use of drilling to provide samples of deep-seated rocks and to permit measurements at the depths where many geologic processes take place.

The petroleum and mining industries have drilled extensively in the past as a part of their exploration programs. In the case of the mining industry these holes have been for the most part confined to rather shallow depths, and in the case of the petroleum industry the holes are mainly in sedimentary basins which make up only a small part of the continental crust. There is great interest within the scientific community, however, in the use of drilling to study the vast, still unexplored parts of the crust including the more ancient and crystalline parts, especially at great depths, and regions that are seismically and volcanically active. Direct measurements of fluid pressures at depth near earthquake faults, and samples of the rocks above and below important seismic boundaries, for example, are needed to resolve questions about earthquake mechanisms and about the geological significance of reflecting layers seen in seismic profiles.

The Foundation now supports a consortium of 33 universities called "DOSECC" (Deep Observation and Sampling of Earth's Continental Crust, Inc.). You will hear more about DOSECC later today--I will simply note that it is patterned after the consortium that manages the Ocean Drilling Program and plays a similar role in the planning and management of NSF-supported scientific drilling on the continents.

The Foundation participates with the Department of Energy and the Geological Survey in an Interagency Accord on Continental Scientific Drilling. These three agencies have agreed to coordinate their research drilling activities and to encourage interagency support of scientific research related to drilling regardless of which agency may fund the drilling itself. There is

an Interagency Coordinating Group which meets frequently, and cooperation among the agencies has been excellent.

The Continental Lithosphere program also supports other large earth science projects designed to make modern geophysical tools for deep sensing available to university scientists. The COCORP project at Cornell University has demonstrated that the seismic reflection profiling technique developed by the petroleum industry can be modified to study the deepest parts of the crust as well as the shallow sedimentary basins. COCORP scientists have discovered large near-horizontal faults along which large segments of the crust have moved hundreds of miles, a body of partially molten rock beneath part of New Mexico, and the geological boundary that marks the place where Africa and North America collided some 300 million years ago. Similar methods are now being used by the NSF-supported CALCRUST group in the southwestern U.S. to study the nature of crustal deformation in that region. The IRIS consortium, made up of 50 universities, is developing seismic instrumentation needed for imaging the deeper parts of the continental crust and the underlying mantle. Using large arrays of digital seismographs, earth scientists employ tomographic techniques (similar to those used for CAT scans of the human body) to produce three-dimensional images of the earth. Other NSF-supported university scientists, working with scientists from the Geological Survey, NASA, and NOAA, use DOD-sponsored geodetic satellites to make direct observations of crustal movements in active regions. Still others study the physical and chemical properties of deep seated rocks in the laboratory.

These approaches, taken together, make an integrated and balanced program of continental studies. None of them alone is sufficient. Drillholes

are essential for calibration of geophysical techniques, but drilling without maximum use of geophysical and surface geological study can be inefficient and wasteful. The Foundation has given special emphasis to this coordinated Continental Lithosphere Program in its budget requests in recent years.

In summary, the Foundation regards scientific drilling on the continents as an important component of its Continental Lithosphere Program and as an appropriate complement to its Ocean Drilling Program. I will be happy to answer any questions you might have.

Senator WARNER. Thank you, Dr. Hays.

Senator Pressler, while we now have Dr. Peck and Dr. Hays here, perhaps we should discuss how they would implement this legislation in a manner not to have budgetary impact. Perhaps you would like to engage in a colloquy with these two witnesses on that point.

Senator PRESSLER. Fine. How would we implement this legislation without a budgetary impact? And, No. 2, I think the international aspects of this, what other countries are doing in this field, would be something of interest. Two points.

Dr. PECK. I think, as you pointed out——

Senator WARNER Dr. Peck, I am going to urge you that that microphone is your best friend. [Laughter.]

Dr. PECK. Maybe, maybe not, Senator. [Laughter.]

As Senator Pressler——

Senator WARNER. If you want your testimony recorded for future generations, it certainly is. [Laughter.]

Dr. PECK. As Senator Pressler pointed out, the operative part of the act has to do with an enhancement of the ongoing coordination between the Department of Energy, the NSF, and the U.S. Geological Survey and would direct that committee to draw up plans and set the budgets for those plans.

At the present time, although there is a fair bit of planning, I do not think we could characterize this as long-term plans or any in any formal sense the drawing up of the plans, the budgets, and the payoff of the program. This would allow us to bring to the attention of Congress the benefits of the program and actually what the plans and attendant costs would be. So, it would enhance the ongoing activity.

Dr. HAYS. I would add to that that we have recently received from DOSECC their operating plan for the next 10 years. That is under review within the Foundation right now. It will also be distributed to other agencies, and we would suppose that that plan would form the basis of our contribution to that.

Senator WARNER. Dr. Stevens, would you be willing to address this question as the leadoff to your testimony? Namely, the budgetary implications in the Department of Energy.

STATEMENT OF DR. DONALD K. STEVENS, ASSOCIATE DIRECTOR, BASIC ENERGY SCIENCES, OFFICE OF ENERGY RESEARCH, DEPARTMENT OF ENERGY

Dr. STEVENS. Yes, Senator, I would be glad to.

The interests of course, and some of the key players in the Department of Energy program are the national laboratories, Sandia, Livermore, Los Alamos, and Lawrence-Berkeley Laboratory. They play a very critical part in particularly the drilling program which the DOE has been most active in. So that it would be necessary that their activities and their contributions be worked into any such plan that might be developed on a cooperative basis across the three agencies.

I think that if one looks at the DOE program, for instance, 59 percent of its funds have been spent through the national laboratories, 17 percent at the universities and 24 percent in industry. The

larger portion to the national labs because of the capabilities of these laboratories to manage drilling, to manage the collections of samples, and so on. It is an independent but cooperative effort that the Department of Energy sees in this field.

Of course, there are strong programmatic interests on the part of the DOE which are the basis for the DOE's role in this program. Waste management, geothermal resource assessment, and getting at the very basics of resource formation are part of the DOE responsibilities.

I would be glad to answer any questions.

Senator WARNER. Well, I think Senator Pressler had another very important question pending for the panel. That was, the other nations of the world and what they are doing of a comparable nature. If each of you could summarize that for a moment.

Dr. STEVENS. I can only speak peripherally on that. There is a program in the Soviet Union—a very deep drilling operation. They have gone further down into the Earth than any other effort that I am aware of in the United States, or, for that matter, in the world. We, in the United States, have not drilled to anywhere near that depth. Perhaps my colleagues could speak on that.

Senator WARNER. What is the depth the Soviet Union has probed?

Dr. STEVENS. That, as I recall, has gone down to something more than 12 kilometers. The deepest hole thus far in the U.S. Continental Drilling Program, the one out at Salton Sea, is just 4 feet more than 2 miles—10,564 feet.

Senator WARNER. And we are at slightly 2 miles? Is that correct?

Dr. STEVENS. Yes. That is a very unusual hole, as we will see, in that it gets down into the thermal region of the Earth's crust. One encounters these very corrosive fluids and very high temperatures which stress our capability to drill in those regimes. It is opening up then new areas for science and technology.

Senator PRESSLER. And we do want to hear the rest of your testimony, but I might bring this in to all of you at this point.

Dr. Peck, in particular, you mentioned that the program, the CSDP, is important to the study of earthquakes and volcanoes. Would it be more helpful giving us greater lead time as to when we can expect them to occur, and pinpointing where they would occur?

Dr. PECK. Well, the important aspect of earthquake studies that we could address with a drill hole is in the zone of earthquake generation. Drilling of the next planned hole should start this fall, under the leadership of the NSF, with whom we are working very closely. The drill hole will go down to a depth of 3 kilometers, very close to the San Andreas fault near Cajon Pass and San Bernardino. That will put us in the zone where there are abundant earthquakes, where we can measure the stresses and stress drops related to those earthquakes, and see what the fluids are and how those fluids facilitate movement along the fault.

It is understanding the phenomena that is going to lead us to be able to predict the phenomena.

Senator PRESSLER. Yes. What do we get out of it besides being able to predict earthquakes and volcanoes, which we do not know, but what will we probably get out of it?

Dr. PECK. Of the program in general?

Senator PRESSLER. Yes.

Dr. PECK. Again, the program in general is going to lead to an understanding not only of the nature of the crust in a number of areas, but also of the processes going on. Although we can get some ideas of what the processes are by studying rocks at the surface and get some ideas of the structure of the crust by doing geophysical studies, the only way to really test it, as Dr. Hays mentioned, is to drill it.

Senator PRESSLER. Yes. So——

Dr. PECK. And by doing the geophysical studies, that should allow us to pinpoint very promising areas and to focus what the nature of the problem is that we can solve by the drilling.

Senator PRESSLER: So there is——

Dr. PECK. Of course there is very widespread interest in continental drilling throughout the world. Dr. Stevens mentioned the Soviet Union's program which has drilled a very deep hole in the Kola Peninsula, but has drilled a number of other holes, a half a dozen or so, in favorable spots throughout the Soviet Union.

West Germany has committed a very large amount of funds to drill a hole deeper than the hole in the Kola Peninsula and are now choosing between two different sites. The French, Great Britain, the Canadians, and many other countries are interested in continental drilling because the world's Earth science community has realized that to really understand the nature of the crust we need to drill at least a few deep holes.

Senator PRESSLER. So there is an analogy between space exploration and CSDP in the sense that we are trying to find what is there, and how might benefit mankind, and so forth. Or is that a little bit of a far-fetched analogy?

Dr. HAYS. I do not think it is, because we probably know more about the surface of some of the planets, and we certainly know more about the sea floor now than we know about the lower part of the continental crust.

Senator WARNER. That is a very interesting point, doctor.

I wonder if I might also draw your attention to an article, and I regret that I am not able to—this is Compressed Air Magazine, April 1986, and I quote:

> To date the deepest hole in the United States is the Bertha-Rogers in Oklahoma, which was drilled to 33,000 feet about 6 miles or 9.6 kilometers, where drilling stopped when the bit ran into molten sulfur.

So maybe that is the record in this country. Does anyone wish to dispute that?

Dr. HAYS. So far as I know, that is the record, yes. That, incidentally, in spite of its great depth, that is still in one of the deeper sedimentary basins. So you are still in the shallow sedimentary part of the crust in that place. There are other places where the ancient parts come nearer to the surface.

Senator WARNER. Now, Dr. Stevens, have we accorded you adequate opportunity to express yourself?

Dr. STEVENS. If I could read just a couple of statements?

Senator WARNER. Of course.

Dr. STEVENS. I have submitted a detailed statement for the record, but I would like to touch on a couple of things we are doing.

It is a pleasure to be here to comment with colleagues from the U.S. Geological Survey and NSF on the Senate bill. We, in the Department of Energy, have been involved in drilling now for some time because of our responsibilities for energy resources, hazardous waste isolation, and so forth.

The mutual interests of the three agencies, DOE, the USGS, and NSF, have been very strong in this area. This mutual interest led to the interagency accord, which has been mentioned. I believe the process of planning the Continental Scientific Drilling Program, as called for in the bill under discussion today, would be a useful additional impetus to this joint planning operation.

The DOE began its scientific continental drilling program in 1979. Of course there was work going on prior to that time that had to do with uranium deposits and so on, but in terms of a scientific research program, DOE's part in the U.S. Continental Scientific Drilling Program really started about 1979. As a consequence of our interest, we started drilling some shallow holes that were identified as being valuable first steps in our study of the continental crust.

Those three were identified as being in the Salton Sea area of California where there is a spreading area of the Earth's tectonic plates. For research on heat and mass flow at two of the largest collapsed volcanoes in the United States, there is one at Long Valley, CA, on the eastern edge of the Sierra Nevada Mountains, and the other at the Valles Caldera in the Jemez Mountains in central New Mexico, just outside of the Los Alamos Scientific Laboratory.

You can see on the collage over here where those three drilling sites are located.

[Collage shown.]

Dr. STEVENS. Those then represent three programs that are underway in shallow drilling. A number of shallow holes have now been drilled and cooperative studies are continuing then on the core samples and fluids which were drawn from them by scientists working under the support of the three agencies, NSF, DOE, and the USGS.

At Long Valley, three holes were drilled into a part of that system known as Mono Domes and very interesting data came forth from these very young—ca. 600 years—flows. These studies confirmed some of the earlier theories that we had about volcanoes, but these studies also provided some new understanding which is still under consideration by the scientific community. That study is still going on.

The deepest and most ambitious U.S. continental drilling project to date is just being completed. That is also located at the Salton Sea near the center of the geothermal energy production zone. That hole was managed and financed primarily then by the Department of Energy's Geothermal Technologies Division under the Assistant Secretary for Conservation and Renewable Resources.

The drilling of the hole, then, that is, the actual drilling expense and so forth, was part of Salton Sea, an applied program of the DOE. There was a strong interaction on the part of people from our scientific program and the scientific programs of USGS and NSF in planning and funding the science that was done on that

hole. The basic research then that is carried out on samples and fluids which are now available as a result of that activity are being studied by scientists supported under the geoscience programs of each of the three agencies. It is a fine example of cooperation and coordination among the three agencies.

I will simply mention some other things that we are doing. The Department has developed an inventory of drill holes nationwide. Policies have been developed for handling and curating cores and samples from drilling operations. These then are in storage at a DOE facility at Grand Junction and are available to the research community of the United States for further study.

Other topics being studied under the Continental Scientific Drilling Program include organic geochemistry, rock permeability and sedimentology, which, of course, are important areas in the context of the fossil energy resources and dealing with the problems of energy-related wastes.

In closing, then, I must stress that this Continental Scientific Drilling Program, is a cooperative effort among the three participating agencies which are well coupled together as a result of the accord and the Interagency Coordinating Committee.

As a final comment with respect to S. 1026, we must recognize that the funding resources for Continental Scientific Drilling should be determined on a year-by-year basis in full consideration of other administration priorities, and the competing requirements for funds in the normal budgetary process.

Section 4(5)(c) would undermine this process. Accordingly, we recommend that this subsection be deleted from the bill. Subject to this deletion, however, we endorse S.1026.

That completes my prepared statement.

[The prepared statement of Dr. Stevens follows:]

STATEMENT OF DONALD K. STEVENS

ASSOCIATE DIRECTOR FOR BASIC ENERGY SCIENCES

OFFICE OF ENERGY RESEARCH

before the

Subcommittee on Natural Resources Development

and Production

of the

Senate Committee on Energy and Natural Resources

July 24, 1986

Mr. Chairman and Members of the Subcommittee:

It is a pleasure to appear here today with representatives from the U.S. Geological Survey and the National Science Foundation to testify in support of Senate Bill 1026.

The Department of Energy has been involved in drilling on the continents in support of its energy technology and national security responsibilities for many years. In recent years, it has become increasingly evident that the solutions to many long-range problems faced by the U.S. in the energy field are dependent upon a sound knowledge and understanding of the continents, the resources contained in them and on a knowledge of continental structure and internal processes. Plate tectonics, a concept that evolved from the ocean drilling program twenty years ago, has revolutionized our thinking about the earth and the way in which we view crustal processes. Because of the success of the ocean drilling program and because the continents host most of the human population of the earth and at least 90% of its energy and mineral resources, we believe that a detailed study of the earth's continental crust is the logical next step. The continental crust is the primary source of the nation's energy and the primary sink for the disposition of wastes from energy use. Thus, increased knowledge of crustal structure and processes is highly important to meeting the nation's future energy needs.

Study of the continental crust is also at the heart of the responsibilities of the U.S. Geological Survey, and is an appropriate activity for emphasis by the National Science Foundation. The strong mutual interests led first

to a large number of meetings and discussions and eventually to the Accord on Continental Scientific Drilling. The interactions among the three agencies have been very effective and fruitful. I believe the process of planning called for in the bill under discussion today will be useful to each of the agencies. My remarks will emphasize the early start the Department of Energy has made in Continental Scientific Drilling, but the future of this national effort needs to be in the hands of all three agencies working closely together.

The Department has supported drilling of the continents for scientific purposes since 1979. The earliest activities were carried out by the Geosciences program in the Office of Basic Energy Sciences. This program took the initiative within the Federal government in arranging for workshops and establishment of a Continental Scientific Drilling Committee under the National Academy of Sciences. The National Science Foundation, the U.S. Geological Survey and the Office of Naval Research also provided support for these efforts. The BES Geosciences program began budgeting explicitly for Continental Scientific Drilling in 1980. Four western DOE laboratories joined together that year in surveys of U.S. thermal regime areas and completed a "Comparative Site Assessment." Emphasis was recommended on studies of the Salton Sea area in California where two continental plates are believed to be spreading apart, and on research on underground heat and mass flow at two of the largest collapsed volcanoes in the U.S.; namely, at Long Valley on the eastern edge of the Sierra Nevada Mountains in California and at the Valles Caldera in the Jemez Mountains in central New Mexico.

Over the next several years, site characterization studies and other geochemical and geophysical research projects were carried out at the Valles Caldera in New Mexico and Long Valley in California, aimed in part at defining specific scientific objectives and locations for subsequent drilling.

As a step toward these deeper objectives, a program of shallow (< 1 km) scientific drilling was started in 1983 and is continuing this year. Apart from the very ambitious and expensive efforts in the Soviet Union, DOE's continental scientific drilling program has proved so far to be perhaps the most fruitful in the world. Three principal drilling operations have been completed. Studies of cores and fluid samples are continuing. At the Valles Caldera, drilling penetrated through the major hydrothermal outflow plume where water is flowing underground away from the central volcanic heat source. At Long Valley, three separate holes were drilled at the edge of the valley where a thin sheet of molten rock was intruded from a deep source only 600 years ago. Sheets of igneous rock formed this way are called dikes. When this particular dike was forming, it broke through to the surface at several places to make a line of large, glassy hills of rock called the Inyo Domes. Holes have now been drilled vertically through the edge of a dome, at a slant through the feeder conduit for this same dome, and at a slant through the dike between two of the domes. The samples show

some features confirming the conventional picture of volcanic processes and other features which were totally unexpected (e.g., low water contents at depth). The third principal shallow drilling operation now completed was designed to measure heat flow at the southeastern part of the Salton Sea; analysis of the data obtained from this drilling is continuing but already there are clear indications that the line of spreading of the upwelling magma and its associated geothermal anomaly is asymmetric and that therefore the size of the geothermal resource is different from our previous understanding.

The deepest and most ambitious U.S. Continental Scientific Drilling project to date is just being completed. The project, called the Salton Sea Scientific Drilling Project, is located near the center of the geothermal energy production zone at the southern edge of the Salton Sea, and is being funded and managed primarily by the Department's Geothermal Technologies Division under the Assistant Secretary for Conservation and Renewable Resources with funding for the associated research projects being shared among NSF, USGS, and the BES Geosciences program. All of the collaborating agencies and scientists have been intimately involved in planning and carrying out the project. The various coordinating and review groups set up to ensure effective collaboration provide a useful model for future collaborations in Continental Scientific Drilling. The hole penetrated over 2 miles (3.2 km) and encountered temperatures in excess of 662^{o}F (350^{o}C). Despite the extraordinarily corrosive conditions and rocks poorly suited for retaining drilling fluids, the operation has been fully successful in

meeting its targets for depth and recovery of samples for research. Major contributions are expected to understanding the geology of continental spreading centers and, more generally, hydrothermal processes in regions of high heat flow.

The BES Geosciences program has also completed a variety of projects to support the overall Continental Scientific Drilling effort. An inventory has been developed of drill holes nationwide as well as comprehensive information data bases for Long Valley, Valles Caldera, and the Salton Sea. Policies have been developed for handling and curating the cores and samples obtained from this scientific drilling and a storage facility is in operation at Grand Junction, Colorado. These samples are available to scientists throughout the United States and elsewhere. An organization at one of the DOE laboratories has been set up to handle the management of drilling operations, related logistics and downhole tool development.

One of the principal topics in DOE's long range research in the geosciences is improved understanding of heat and mass transfer processes in various thermal regimes of the earth. As indicated by the work I just described, research on this topic is a central focus of DOE's Continental Scientific Drilling. Under the Interagency Accord, DOE has accepted primary responsibility for drilling and related logistical costs in thermal regime areas. Much of the research made possible by the drilling in these areas will also be funded by DOE, but a variety of additional research efforts are likely to be of interest to NSF and USGS and funded by them.

Since hostile environments such as those encountered in thermal regimes pose formidable technological challenges, we can expect direct industrial applications to stem from new approaches to drilling, logging, sampling, data analysis, and instrument development.

Other major topics in DOE's geosciences research include organic geochemistry and sedimentology which provide understanding important in use of fossil energy resources and in dealing with many energy related wastes. Important opportunities for research in these areas can be expected to arise appropriate for inclusion in DOE's Continental Scientific Drilling program in future years.

Over the years, during and since World War II, the U.S. has built a scientific and technological resource in its DOE National Laboratories which is, I believe, second to none. These laboratories, in addition to their science and engineering expertise, have an ability to respond rapidly on applied problems. This capability, when coupled with the capabilities of the energy and mineral industry and with university geoscientists, constitutes a very powerful combination to tackle the problems, some of which may be of overwhelming complexity in penetrating the earth's continental crust and encountering the very great stresses, high temperatures and corrosive environments of the earth's thermal regimes. The availability of these DOE laboratories, and the high relevance of the study of the continental crust to the Department's energy resource and energy-

related waste isolation missions, were factors in determining that the Department of Energy should participate early and strongly in continental scientific drilling.

It is clear from the foregoing that the Department of Energy has played a leading role in establishing a credible effort in continental scientific drilling. Recognizing, however, the importance of pulling together a cooperative national effort, the Department initiated an Accord on the subject with the U.S. Geological Survey and the National Science Foundation which was signed in April, 1984. The Accord defines the framework for a cooperative interagency effort in scientific drilling on the continents. All projects that are part of the national CSD program are included as a supplement to the Accord by action of the Interagency Coordinating Group (ICG), which serves as a steering group for the national program. Participation is open to other interested Federal agencies. The Accord helps assure that the activities of the participating agencies in a variety of Federally-supported scientific projects involving continental scientific drilling are fully coordinated.

In closing, I want to emphasize again that continental scientific drilling is a cooperative effort among participating agencies, each with its own interests and priorities, each with a different constituency. Depending on the agency, the proposals are handled with similar science priorities, but differing views of mission-relatedness. This, I believe, is healthy. The

program will be stronger and broader than it would be if funded by a single agency.

Pluralism is an essential feature of the Interagency Accord and a valuable tradition in Federal support for fundamental research. For a major scientific undertaking, such as continental scientific drilling, pluralism:

(a) provides independent channels for support of investigator-initiated research;

(b) matches the realities of the way budgets are developed;

(c) assures the broadest input of relevant scientific and technical interests;

(d) helps keep mission agency research focused on agency missions; and

(e) helps to assure optimum scientific progress by bringing to bear the latest advances in engineering and technology, otherwise not generally available.

Thus far, the ICG has proved effective in handling problems of interagency coordination as they have arisen. Together, the agencies seek to marry the basic science interests of the scientific community to the more practical objectives of industry and to their own applied activities so as to optimize the return on the public investment.

Finally, with respect to S. 1026, we must recognize that the funding resources for continental scientific drilling should be determined on a year-by-year basis in full consideration of other Administration priorities and

the competing requirements for funds in the normal budgetary process. Section 4, Subsection 5(C) would undermine this process. Accordingly, we recommend that this subsection be deleted from the bill. Subject to this deletion, we endorse Senate Bill 1026.

Senator PRESSLER [presiding]. Thank you all very much.

Dr. Stevens, you mentioned geothermal resource assessment in your testimony. Do we have a good idea of the amount of geothermal resources out there today? Would CSDP research be beneficial in that respect?

Dr. STEVENS. I am not in a position to answer that we know. I do not suppose we really do know all of the resources out there, and that is part of our program responsibilities, to be able to identify by new techniques what the boundaries and what the total resource value is at a given point.

So I think that there is not a good, sound answer on how much there is out there. I certainly believe that the Continental Scientific Drilling Program will contribute handsomely to the unfolding of that picture, and that is a major reason of the DOE's participation in the program.

Dr. PECK. If I might comment, Senator, we, in the Geological Survey, have made estimates of geothermal resources, and actually one of the later speakers, Dr. Carel Otte from Union Oil, can speak very knowledgeably on that subject. But estimates of undiscovered resources, be they petroleum, minerals, or geothermal energy, are only guesstimates. Often, the indications of geothermal energy at depth are swamped out by cool water at the surface, for example in the Cascade Range, and the only way to really determine those resources is by drilling.

Senator PRESSLER. I think the testimony we have heard here is very helpful, and your statements will be read by the Senators. I thank this panel very much. We may call on you for additional questions, but at this point I would call panel two forward, unless staff or Senator Warner or Senator Nickles has some questions. Are there any other questions?

[No response.]

Senator PRESSLER. I thank you very much.

We will call the second panel forward: My friend, Dr. James Papike, Institute for the Study of Mineral Deposits, South Dakota School of Mines and Technology; Dr. C. Barry Raleigh, director, Lamong-Doherty Geological Observatory and Department of Geological sciences, Columbia University; Dr. Frank Stehli, chairman, College of Geosciences, University of Oklahoma; and Dr. William L. Fisher, Bureau of Economic Geology, University of Texas.

Why do we not proceed with the man who started all this off, James Papike.

STATEMENT OF DR. JAMES J. PAPIKE, INSTITUTE FOR THE STUDY OF MINERAL DEPOSITS, SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY

Dr. PAPIKE. Thank you very much, Senator Pressler.

I am pleased to testify today on behalf of the Continental Scientific Drilling and Exploration Act. In my capacity as a professor from South Dakota, it has been a distinct pleasure to have the opportunity to work with Senator Pressler and his staff on this important legislation. Not since my intimate involvement with NASA in planning and executing the Apollo missions to the Moon have I felt such excitement and momentum for a national scientific pro-

gram. In my concluding remarks today I will draw some analogies between these two program.

I am now going to digress from my typed statement because I perceive here that the speakers both before me and after me are not really starting early enough in this whole process, so I would like to go back to 4.6 billion years ago—namely, the origin of the solar system. That seems a long way to go, and it maybe seems off the mark, but I think it is not, and it is not very complicated.

At 4.6 billion years ago our solar system formed, and the planets as well, from a solar disk of debris. This debris had a composition called carbonaceous chondrites. Carbonaceous chondrites are very old meteorites. They are 4.6 billion years old. In other words, they are as old as the solar system. They have the same composition as the Sun, minus the volatile elements helium, hydrogen, and some of the other volatile elements.

So it was in this environment 4.6 billion years ago that the planets formed. Now the inner planets, the four inner planets called the terrestrial planets of Mercury, Venus, the Earth, and Mars, have many similarities in that they are silicate rich and they are rocky.

Now they formed by a process that we now mostly agree was a process called homogeneous accretion. That means that particles gathered together and built up in a snowball-type fashion—of course they were much warmer—of particles that were all the same in composition until the planets finally accreted and collected the material around them until they obtained their size.

Now if we stopped right there at 4.6 billion years ago, all the inner planets would be roughly the same composition. The outer parts and inner parts would be identical, and you would not need a Continental Scientific Drilling Program. So what has happened to the planets from 4.6 billion to now that makes our task so difficult?

Well, there are at least three sources of heat in our early planet: the heat of accretion; the heat buildup of radioactive decay—potassium, uranium, and thorium generate heat; and we now know because of the study of the Moon that the planet Earth experienced intense meteorite bombardment from 4.6 to 4 billion years ago. So it got hot. It got hot enough to start melting the interior and formed the process of vulcanism, no different from what goes on in Hawaii practically every day. The rocks that come to the surface from the melting of the interior are basaltic rocks. They are dark. Almost all of you know what they look like.

Basaltic rocks are not continental crust. So clearly something has to happen to these rocks to fractionate them or change them to make the continental masses. Now what happens is when basalt comes to the surface it forms rigid plates; it hardens and it cools and we have rigid plates.

Within the mantle we have a process called "convection." Convecting cells come up, move out, and when they come up they crack, there is rifting, basalts come up along it, and these basaltic plates ride on the top of the convecting cells, different cells start in different places, so these basaltic plates bump into each other.

Every time they bump into each other, one plate rides over the other. The one that is ridden over goes down into mantle depths or is subducted and it is remelted. It is destroyed. But during this,

again we melt the basalts that fractionate to form more silicate rich materials much more similiar now to continental crust. So we have started the process.

Now the process of plate tectonics is going on right now. Basaltic plates are hitting basaltic plates. Basaltic plates are hitting continental plates. Continental crust is lighter. It is lower density, so it always rides on top. It floats like foam on the ocean. Once it forms, it stays there. So you keep adding on. They accrete outward, continents do, from at least 4 billion years ago. The Earth is 4.6, so that is about 87 percent of Earth's history is locked into the continents.

On the other hand the oceans made up of oceanic plates destroy each other. The oldest plate in the ocean is about 200 million years. So the ocean history is very young. Continental history is very old.

Now because of this very complicated process of growth over a long period of time and collision, the continents are very, very complicated. On the other hand, they are very, very important. It is not only where mankind resides, but it is the source of geothermal resources. It is the source of many rich mineral deposits that form by fractionation in the formation of the continents.

So in a sense, and in an overview fashion, that is why they are so important. They are important because they are important historically, because they are old, they lock in the history of the Earth, but they are important because they hold mineral deposits, and of course hazards—volcanic hazards, Mt. St. Helens, the earthquakes in California, and the like.

So that is a rather brief overview. I will go back now to my prepared statement.

Therefore, continental crust is quite thick. It is 30 to 50 kilometers, or 20 to 30 miles, compared to oceanic crust of 10 kilometers or 6 miles. This thickness, combined with the complicated structure of continental masses, poses an extreme challenge to the geoscientist who is trying to understand the origin and evolution of such masses, their states of stress which might lead to earthquakes, their hidden concentrations of valuable elements, their present accregional/dynamic borders where explosive volcanism takes place—for example, Mt. St. Helens—and sources of geothermal energy resulting from heating of deep circulating water by molten rock.

The challenge of truly understanding the geology of the continents can be addressed by a number of approaches, including the obvious mapping and sampling of exposed rocks. Also, sophisticated geophysical techniques mentioned by the previous speakers, namely deep seismic profiling, is also very useful.

However, despite such sophisticated techniques, in the end we simply must sample by drilling of the rock/fluid mass and make measurements both at depth in the Earth's continental crust, and on rock and fluid samples brought back to the surface. There is truly no other way to gather certain types of essential information.

My preceding statement outlines in overview fashion our current understanding of how continents form and evolve. Much of the research involved with such problems is truly basic. However, I must point out that it is through this basic understanding that effective practical application is derived.

Understanding of the processes of continental growth and evolution leads to more effective exploration for ore deposits, to better predictive capability and mitigation of volcanic hazards and earthquakes, to better utilization of geothermal resources, and safer storage of hazardous waste materials.

Last, some analogies to the lunar program. The Apollo Program to the Moon addressed such important questions as the origin and evolution of our solar system and many exciting answers to important broad questions have resulted. However, study of our Moon has also given important insight into the early history of the Earth, a portion of the Earth's history that has been lost because the rock record has been erased in our active planet.

For example, we learned that the first 600 million years of Earth's history were dominated by meteorite bombardment. This bombardment caused heat production which helped activate early terrestrial dynamic activity. Also we benefited tremendously from the technological spinoff of the Apollo Program.

The same type of technological spinoff can be expected from the Continental Scientific Drilling Program. Just as our Apollo Program helped us in the exploration of outer space, our Continental Scientific Drilling Program will aid greatly in our exploration of the Earth's inner space. Continental Scientific Drilling is a concept whose time has come. It is the reason that we are gathered here today, and speakers who will follow will talk about the details of the program.

I thank you.

[The prepared statement of Dr. Papike follows:]

Hearings on S. 1024 (Continental Scientific Drilling and Exploration Act) before Natural Resources Development and Production Subcommittee, Senate Energy and Natural Resources Committee, July 24, 1986

Testimony by Dr. James J. Papike
Institute for the Study of Mineral Deposits
South Dakota School of Mines and Technology
Rapid City, South Dakota 57701-3995

"Origin and Evolution of Continental Crust"

Chairman Warner, Senators, and Staff:

I am pleased to testify today on behalf of the Continental Scientific Drilling and Exploration Act. In my capacity as a Professor from South Dakota, it has been a distinct pleasure to have the opportunity to work with Senator Pressler and his staff on this important legislation. Not since my intimate involvement with NASA in planning and executing the Apollo missions to the moon have I felt such excitement and momentum for a national scientific program. In my concluding remarks today I will draw some analogies between these two programs.

At approximately 4.6 billion years ago our solar system was born. The sun and the cloud of gas and dust from which it and the planets formed set the stage for planetary formation and evolution. The inner planets, Mercury, Venus, Earth and Mars, are referred to as the terrestrial planets because they are all similar to the Earth in terms of their rocky surfaces and abundant silicate minerals. Although planetary formation and growth has generated ongoing debate, a variation of a model entitled "homogeneous accretion" is generally accepted. Simply put - the model states that the terrestrial planets all formed from particles and fragments in the solar cloud, or nebula that are of composition similar to carbonaceous chondrites. Carbonaceous chondrites are primitive meteorites (4.6 b.y. old) that have essentially the same composition as the sun minus the light, highly volatile components, for example, hydrogen and helium. Thus the

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planets grew in a cooling solar nebula from fragments that were similar in composition. The planets so formed were initially homogeneous, i.e. their inner and outer zones were of essentially identical composition. At this time, still very close to 4.6 billion years ago, the earth did not have a well developed crust, mantle, or core. No oceans existed and no valuable concentrations of elements or mineral deposits had yet formed.

However, this condition of the earth was short-lived because of the heat obtained by: 1) the process of accretion; 2) by continued meteorite bombardment from 4.6 to 4.0 billion years ago (our first 600 million years of existence as a planet); and 3) by radioactive decay of certain radioactive elements like uranium, thorium, and potassium, which caused melting of inner portions of the earth and degassing of components including water. These heat-induced processes led to fractionation of elements, meaning that certain elements group together and are carried upward to the earth's crust in basaltic volcanic rocks or volcanic gases while others are left behind in their mantle sources.

Convection took place in the earth's mantle and basaltic rocks rose along the upwelling cells. These basalts came to the surface along long narrow fractures (rifts), cooled and were carried outward from the rift in conveyor belt fashion. These large areas of basalts, that were mantle-derived, on cooling formed relatively rigid plates that rode on the surface of the earth until they collided with another basaltic plate. When they collided, one plate rode over the other. The down welling or subducted plate entered a higher temperature regime deep below the surface and was melted. Note Figure 1. This is a second major melting event. The first was the melting of the mantle to produce basalt while the second was the melting of basalt to produce continental crustal rocks, for example, granites, that are rich in elements like silicon, aluminum, potassium,

sodium, etc., as well as other elements that ultimately concentrate and form ore deposits.

The life span of the basaltic plates that underlie the oceans is rather short -- a maximum lifetime of ~200 million years before, on collision with another plate, they are again driven downward only to be remelted. The continental plates, however, made up of lighter, low-density material constantly ride near the surface and float like foam on the ocean. In each collision with a basaltic or oceanic plate the lighter continental plate rides over the denser plate. Thus once formed, continental masses persist and evolve and fractionate to form ore deposits. When continental plates collide with continental plates, neither is easily subducted because of their low density, and extensive folding and mountain building ensue. The Himalayan mountains are an example. Note Figure 2. Thus the continental masses are much older than the oceanic crust, having formed and evolved over the last four billion years or ~87% of earth history. The continental masses are very old, very complicated, and very important for it is here where mankind resides.

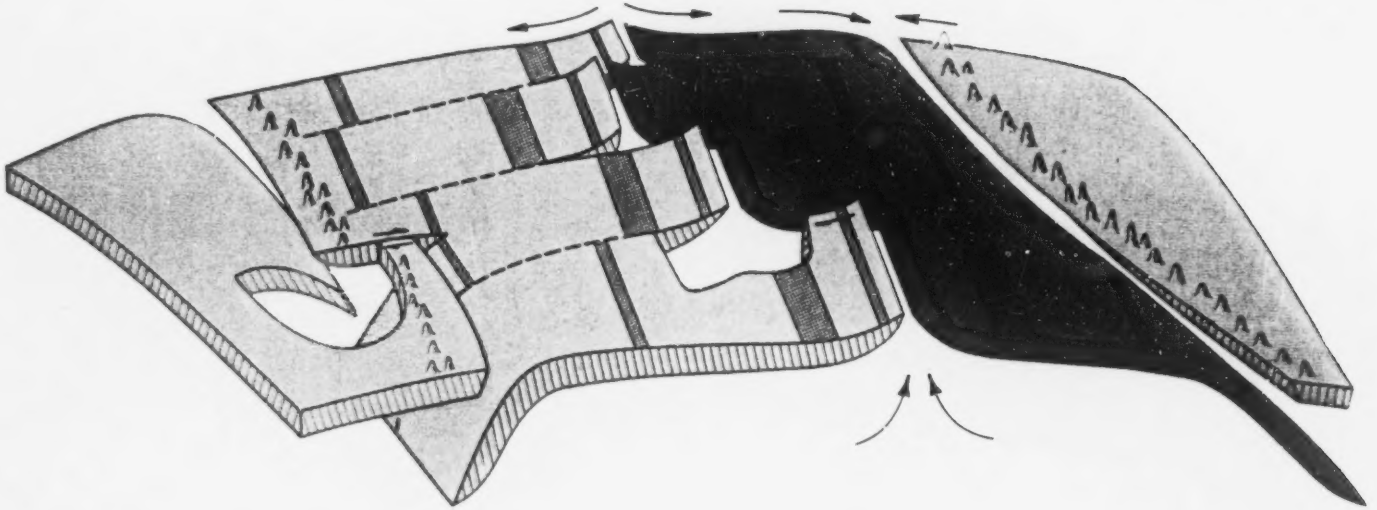
Continental crust is quite thick (~30 to 50 km or 20 to 30 miles) compared to oceanic crust (~10 km or 6 miles). This thickness, combined with the complicated structure of continental masses, poses an extreme challenge to the geoscientist who is trying to understand the origin and evolution of such masses, their states of stress which might lead to earthquakes, their hidden concentrations of valuable elements, their present accretional/dynamic borders where explosive volcanism takes place (for example, Mt. St. Helens) and sources of geothermal energy resulting from heating of deep circulating water by molten rock. The challenge of truly understanding the geology of continents can be addressed by a number of approaches including the obvious mapping and sampling of exposed rocks

fortuitously brought to the surface by past dynamical processes. Also, sophisticated geophysical techniques using energy sources such as earthquakes or artificial means are capable of imaging deep structures. This new initiative of deep seismic profiling is indeed a major technique in elucidating the nature of the deep crust. However, despite such sophisticated techniques, in the end, we simply must sample by deep drilling of the rock/fluid mass and make measurements both at depth in the earth's continental crust and on rock and fluid samples brought back to the surface. There is truly no other way to gather certain types of essential information!

The preceding statement outlines, in overview fashion, our current understanding of how continents form and evolve. Much of the research involved with such problems is truly basic. However, I must point out that it is through this basic understanding that effective practical application is derived. Understanding of the processes of continental growth and evolution leads to more effective exploration for ore deposits, to better predictive capability and mitigation of volcanic hazards and earthquakes, to better utilization of geothermal resources, and safer storage of hazardous waste materials.

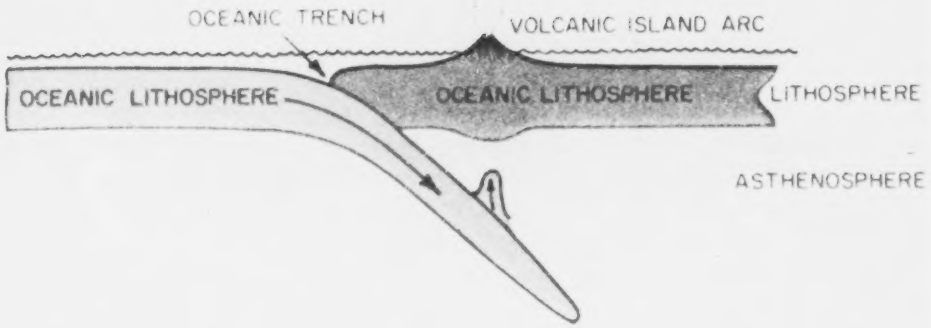
Lastly -- some analogies to the lunar program. The Apollo program to the moon addressed such important questions as the origin and evolution of our solar system and many exciting answers to important broad questions have resulted. However, study of our moon has also given important insight into the early history of the earth, a portion of earth history that has been lost because the rock record has been erased in our active planet. For example we learned that the first 600 million years of earth history were dominated by meteorite bombardment. This bombardment caused heat production which helped activate early terrestrial

dynamic activity. Also we benefited tremendously from the technological "spinoff" of the Apollo program. The same type of technological spinoff can be expected from the Continental Scientific Drilling Program. Just as our Apollo program helped us in the exploration of outer space, our Continental Scientific Drilling Program will aid greatly in our exploration of the earth's inner space. Continental Scientific Drilling is a concept whose time has come. It is the reason that we are gathered here today and speakers who follow will talk about the details of the program. Thank you.

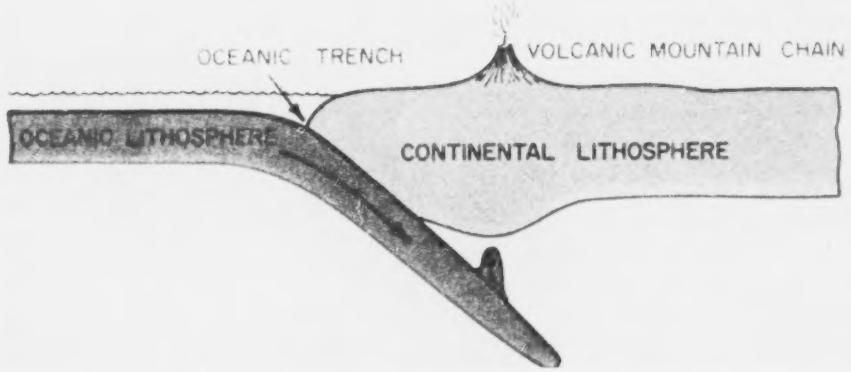


After Sawkins, et al., Fig 5-15 , p.134

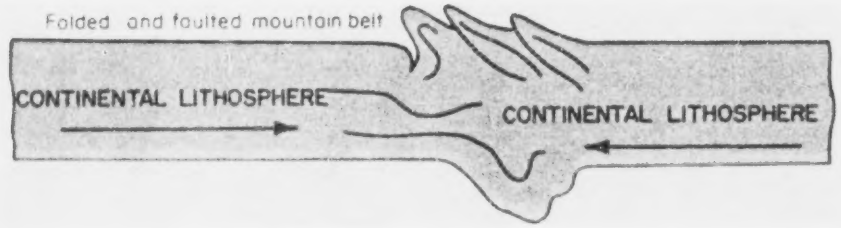
A. Collision of two plates, both with oceanic lithosphere



B. Collision of two plates, one oceanic and one continental



C. Collision of two plates, both with continental lithosphere



After Sawkins, et al., Fig. 5-11, p.128

Senator PRESSLER. Thank you very much.

I will next call upon Dr. C. Barry Raleigh, director of the Lamont-Doherty Geological Observatory at Columbia University. By the way, we will put your entire statement in the record. If you can, summarize as much as possible the main highlights.

Dr. Raleigh.

STATEMENT OF DR. C. BARRY RALEIGH, DIRECTOR, LAMONT-DOHERTY GEOLOGICAL OBSERVATORY, COLUMBIA UNIVERSITY, AND CHAIRMAN, BOARD OF DIRECTORS OF DEEP OBSERVATION AND SAMPLING OF THE EARTH'S CONTINENTAL CRUST, INC.

Dr. RALEIGH. Thank you, Senator Pressler.

Before I start to summarize my statement I would like to point out that in the last published copy of the Supplement, Science and the Future, for Encyclopedia Britanica there is an article on drilling the Earth's deepest hole. I do not know if the U.S. Senate does, but I believe anything that I read in the Encyclopedia Britanica. So I would be pleased to offer copies to the committee.[1]

Senator PRESSLER. If it is a brief article, we shall place it in the record, and we appreciate it very much. I think staff has that, but we very much appreciate that.

Dr. RALEIGH. Thank you.

Now I was asked to describe the history, and I will do so briefly, of the Ocean Drilling Program, formerly the Deep Sea Drilling Program. It was begun in 1966 with the notion that the Earth's oceans were relatively unknown, and the oceanic crust beneath them poorly understood. The mantle below that was rather close to the surface by comparison with the continents.

Four of the major oceanographic institutions in the United States at the time organized a program to begin to try to drill holes initially at least to try to drill to the mantle of the Earth, but for a variety of reasons they gave up on that and began to drill throughout the ocean crust.

The program was begun at a remarkable period in the evolution of what we understand now about the Earth and how it deforms and how the plates of the Earth move around relative to each other. At the point when the drilling program began, most of the geophysicists and geologists involved were convinced that the oceans were permanent. That is to say, that they had sat there throughout the history of the Earth, and in fact the drilling program was the first absolute proof that the oceans were quite young, and in fact that they got younger and younger as the drill holes approached the mid-ocean ridge axis where hot material flows up, pushes the ocean crust and upper mantle sideways to its point of collision with the continental masses.

The Ocean Drilling Program has done a great deal more. This notion that we can drill relatively shallow holes and learn a great deal for example in the case of the oceans about the past climates of the Earth, there are extraordinarily detailed records of the isotopic composition of shells that die and fall down and are collected

[1] The article was retained in subcommittee files.

on the ocean floor. We have now developed theories of the variations in the Earth's climate that have been confirmed through ocean drilling.

It has been a program of remarkable international cooperation. There are five additional member nations and a consortium of European nations, each of whom contribute financially to the Deep Sea Drilling Program, and substantial financial contributions. So the international aspects of the Deep Sea Drilling Program and now the Ocean Drilling Program are extremely important.

I would like to say just a couple of words about the degree of concensus within the scientific community outside of the Federal agencies. I should tell you that continental scientific drilling has been on people's minds for a long time. As early as 1974 the Carnegie Institute of Washington organized a meeting at Ghost Ranch, NM. There was a considerable enthusiasm amongst the scientists there to begin to apply to the scientific problems of the origin of the continents the tools and techniques that the drilling industry had developed for oil exploration.

The report was published, followed by yet another conference at Ghost Ranch in 1978. By 1980 the National Academy of Science had established a Continental Scientific Drilling Committee to consider the problem. They are producing their report now, and are I would say enthusiastic that we now need a Continental Scientific Drilling Program.

Finally, the National Academy's Board on Earth Sciences, which is the overseeing Board, recommended in its report, "Opportunities for Research in the Geological Sciences," that continental scientific drilling was a program whose time had come.

Let me just conclude quickly by giving you my own personal view of one reason why I think the program is really extremely important.

I began work as a laboratory scientist, and one of my interests was trying to make earthquakes in the laboratory. We need to know a number of things about the materials. Rocks are not as simple as a lot of other materials. They are full of fluids. They are highly stressed. When they rupture, you can actually begin from doing laboratory experiments to determine what it is that controls that point of rupture. But all of those properties, the temperature, the kind of rock, the state of stress, the fluid pressure, have to be known in order to make some prediction of the actual failure process and the timing of a great earthquake.

We know none of those properties in the deep parts of the San Andres Fault. I can tell you that there is a very strong consensus among earthquake research scientists that in the next 50 years that southern California will undoubtedly experience a great and calamatous earthquake. The time is on us to begin to find out as much as possible about the system that makes that great earthquake as we can. Deep drilling should permit that.

Thank you.

[The prepared statement of Dr. Raleigh follows:]

STATEMENT OF

DR. C. BARRY RALEIGH

Director, Lamont-Doherty Geological Observatory
of Columbia University
and
Chairman, Board of Directors of
Deep Observation and Sampling of the Earth's
Continental Crust, Inc. (DOSECC)

Regarding

"THE CONTINENTAL SCIENTIFIC DRILLING
AND EXPLORATION ACT", (S. 1026)

Submitted to the

Subcommittee on Natural Resources Development and Production

of the

Senate Committee on Energy and Natural Resources

July 24, 1986

TESTIMONY FOR SENATE HEARING ON BILL 1026

by C. Barry Raleigh
Director
Lamont-Doherty Geological Observatory
of Columbia University

Since Colonel Edwin Drake's first oil well hit "black gold" at a depth of 21 meters in Titusville, Pennsylvania, in 1859, the Earth has been repeatedly penetrated by progressively deeper drill holes. Between 1970 and 1985 oil and gas wells drilled in the United States alone, if laid end to end, would reach more than twice to the Moon and back. In the continuing search for oil and gas, the difficulty in finding easily accessible reserves in the U.S. has led to wells deeper than the height of the Earth's tallest mountains. While exploring for natural gas in sedimentary rock, those sinking the Bertha Rogers well in Oklahoma encountered molten sulfur before drilling was finally terminated at 9,600 meters. Since one meter equals about 3.3 feet, this was nearly six miles.

Nearly all of the wells drilled to depths greater than one kilometer (about 0.62 miles) have been in comparatively soft sedimentary basins--ancient seafloor depressions formed by downbuckling or rifting apart of the crust and filled with oceanic or lake-deposited sediments that eventually hardened to rock. As a consequence, geologists working closely with commercial drilling operations have learned a vast amount about sedimentary rocks and the conditions of their deposition and subsequent history. Extremely sophisticated instruments have been developed to permit remote measurements of the state of the rocks and the fluids within them by lowering the devices on cables down the holes. Samples of the rocks can be retrieved during or after drilling. When an exploratory hole is drilled today for oil or gas, geologists are able to determine the age, mineral constitution, and physical and chemical properties of the rocks encountered.

They know the volume of pore space within the rocks and the nature of the fluids--whether oil, gas, or saltwater--within the pores. The pressure within the pore fluids, the rate at which they flow through the rocks, and much more can be determined. With all this technology for both drilling and scientific observation so readily available, scientists are understandably eager to put it to use in exploring the Earth's crust to solve some of the most exciting mysteries of the formation and evolution of the continents.

The success of seafloor drilling

Another source of inspiration and experience for the still fledgling enterprise of deep continental drilling comes from the well-seasoned Deep Sea Drilling Project (DSDP), undoubtedly the most successful large-scale international cooperative research program yet undertaken. The DSDP began with the notion that a deep hole through the relatively thin crust (about five kilometers) of the ocean floor would penetrate the underlying, dense mantle rock of the Earth. Project Mohole, as it was originally known, never came to pass, but a new concept, that of drilling and sampling the sediments covering the floors of the world's oceans gained widespread support. The DSDP was begun in 1966 by four major U.S. oceanographic isntitutions: the Lamont (now Lamont-Doherty) Geological Observatory, Palisades, New York; the Scripps Institution of Oceanography, San Diego, California; the Woods Hole (Massachusetts) Oceanographic Institution; and the School (now Rosenstiel School) of Marine and Atmospheric Science of the University of Miami, Florida.

The timing of the DSDP was remarkable. Until the early 1960s scientists generally believed that the oceans were permanent features of the Earth's surface and that the history of the Earth since its beginnings was recorded within the

slowly accumulating blanket of sediment overlying the oceanic crust. At that time, however, evidence had begun to convince many that the continents and the oceanic crust had been moving slowly, colliding at the deep-sea trenches along the continental margins and pulling apart to create new oceanic crust along the mid-oceanic ridges. Indeed, the first and most dramatic result of deep-sea drilling showed that the volcanic crust of the Atlantic Ocean grew progressively older, from nearly zero along the axis of the mid-Atlantic Ridge to a maximum age of 180 million years at the extreme edges near the margins of the continents. Not only did drilling eventually reveal that the ocean floors are the least permanent features of the Earth's surface, less than 5% of the age of the planet, but it also confirmed beyond doubt the hypothesis of seafloor spreading. New crust is found at the ridges where hot, upwardly convecting rocks of the oceanic mantle give up their molten fractions of basalt in eruptions. The convective motion carries a comparatively thin, 50-kilometer-thick plate of cooling oceanic crust and underlying mantle (lithosphere) to the margins of continents; there the plate disappears, diving (subducting) beneath the continent at deep-sea trenches attended by violent earthquakes and volcanic eruptions.

Much more has been learned in the subsequent years of the DSDP, which has collected a total of 100 kilometers of core from 637 sites drilled during 96 legs. Earth scientists can reconstruct the climates of the past from the isotopic records stored in shells of plankton raining down on the ocean floors for thousands of millenia. The heat stored in the fractured volcanic crust near the oceanic ridges is now known to drive the convective circulation of vast quantities of ocean water through the crust. While in the crust the water collects soluble metal sulfides and, upon returning to the ocean as superheated steam at the ridge axis, deposits rich bodies of ore--someday, perhaps, to be mined by humans.

Continental Scientific Drilling - A Consensus among Scientists

Earth scientists in the United States, the USSR, Canada, Western Europe and Japan have now turned to deep scientific drilling as the essential means for understanding the history, structure and processes of the evolution of the continents.

This scientific consensus was clearly evident in a May, 1984 International Symposium on Observation of the Continental Crust through Drilling, held at Tarrytown, N. Y., sponsored by Lamont-Doherty Geological Observatory of Columbia University, the Continental Scientific Drilling Committee, and the Coordinating Committee on Continental Drilling of the Inter-Union Commission of the Lithosphere, and supported by the Department of Energy (DOE), the United States Geological Survey (USGS) and the National Science Foundation (NSF).

The Symposium provided only the most recent major forum for expressing the need for a scientific program of continental drilling; in the United States such a program has been recommended by a series of notable scientific committees over the past ten years. At Ghost Ranch, N.M. in 1974, a Carnegie Institution workshop on continental drilling identified major scientific questions that required drilling for their answer. A second workshop was held at Los Alamos, N.M. in 1978, under the sponsorship of the U.S. Geodynamics Committee, and its results were published by the National Academy of Sciences/National Research Council (NAS/NRC) as a report on the Continental Scientific Drilling Program. In January, 1980 the NAS/NRC established the Continental Scientific Drilling Committee (CSDC) to guide the planning for a national program of scientific drilling, and its detailed report is imminent.

The consensus on the need for a program of scientific continental drilling

is shared by a number of federal agencies, especially the Department of Energy (DOE), the Department of the Interior/United States Geological Survey (DOI/USGS), the Department of Defense (DOD), and the Nuclear Regulatory Commission (NRC). Their missions involve pressing social and economic issues that require detailed information which can only be obtained by drilling into the continental crust. Notable examples are the safe disposal of hazardous wastes, the prediction of earthquakes, the estimation of earthquake risk, and the exploration and exploitation of new energy and mineral resources.

Thus in 1977, recognizing the multi-agency interests in scientific continental drilling, an ad hoc Panel on Continental Drilling of the Federal Coordinating Council of Science, Engineering and Technology (FCCSET) Committee on Solid Earth Sciences prepared a set of recommendations for federal action. The panel concluded that a five-to-ten-year National Continental Drilling Program should be established along the lines recommended by the report from the 1974 Carnegie Institution workshop.

In 1983, the NAS Board on Earth Sciences recommended in its report, Opportunities for Research in the Geological Sciences that a program of deep continental drilling be initiated. The NAS/NAE Committee on Science, Engineering and Public Policy (COSEPUP) appointed a Research Briefing Panel that year to brief the President's Science Adviser and the staff of the Office of Science and Technology Policy on the Solid Earth Sciences. The Briefing Panel recommended an NSF-funded, dedicated continental drilling program in support of numerous research activities.

Recognizing the need for coordinating their mutual interests in continental scientific drilling, an Accord was signed in April, 1984 by NSF, DOE and DOI/USGS, establishing a formal mechanism for cooperation and coordination through the Interagency Coordinating Group.

To conclude my testimony, I will give an example of how deep drilling will play a vital role in the continuing revolution that the earth sciences are experiencing. We know with as much certainty as scientists can ever forecast the future, that southern California will experience a great and calamitous earthquake in the next 50 years. It will probably be sooner than that but the longer it waits, the greater the damage and loss of life will be.

To predict when and where the earthquake will occur can reduce dramatically the worst effects - fires, deaths from occupancy of unsafe structures, and floods from failure of unsafe dams. A host of preparatory life-saving measures can be taken. But prediction is notoriously difficult because, despite much laboratory and theoretical work and years of observation of the behavior of active faults from the surface, we do not know the deep inner workings of the unstable machine that is the San Andreas Fault. Direct sampling and observation at the depths where large earthquakes initiate can tell us the necessary vitally important parameters. What is the temperature, the state of stress, the mechanical properties, the pressure and volume of the fluids in the fault? Currently none of these quantities can even be guessed. With a few deep holes at critical points, we should learn what it is that causes the final and deadly instability. Without deep drilling scientists will be clutching at too few straws to make a reliable prediction of the onset of California's next great earthquake.

As the particle accelerator is to physicists and the telescope to astronomers, the drill is the means for geologists to explore into the third dimension of the continents. Thanks to our need for oil and gas, the machinery is at hand to do so. Mankind can look forward to better ways of searching for minerals and fossil fuels, of disposing of radioactive wastes, and of predicting the certain and calamitous earthquakes of the future. Perhaps just as importantly, understanding the planet we live on will be a lasting bonus to future generations.

Senator PRESSLER. Let me say at this point that I am going to have to run to another committee. I have a Harvard Law School professor whom I persuaded to come down here to testify before another committee, and he is over there. But I want to say I think that what these witnesses are saying, I think that this hearing, this effort parallels in importance our efforts in space. We know previous little about the world below us. We need to know more about energy resources, minerals, earthquakes, volcanoes, history and basic sciences, and I think we should spend some time exploring what is below us also. This panel is dedicated to that.

So I am going to go for awhile and try to come back. Let me say it is very important to my State and it is important to the School of Mines, and it is important to our country's scientific development, and I am very proud of the witnesses and of the committee for holding this hearing.

Senator WARNER [presiding]. Senator, before you leave, I understand it was Dr. Papike who came into one of your field offices, to your offices in your State, and initiated the thinking that led to this hearing. Is that correct?

Senator PRESSLER. That is right. He walked into our Rapid City field office with the idea. I hope we are responding appropriately. So if you have a good idea, sometimes it is good to walk into one of your Senator's field offices. So I am very proud of your efforts.

Senator WARNER. Thank you.

Dr. Stehli.

STATEMENT OF DR. FRANCIS G. STEHLI, CHAIRMAN, COORDINATING COMMITTEE NO. 4 (CONTINENTAL DRILLING OF THE INTERNATIONAL COMMISSION ON THE LITHOSPHERE), AND CHAIRMAN, SCIENCE ADVISORY COMMITTEE OF DEEP OBSERVATION AND SAMPLING OF THE EARTH'S CONTINENTAL CRUST, INC.

Dr. STEHLI. Yes, sir. I am Frank Stehli from the University of Oklahoma, and I would like to address particularly the question Senator Pressler asked about what other countries are doing in the field of scientific drilling.

Senator WARNER. If you would, draw that microphone just a little closer. Thank you.

Dr. STEHLI. In our world of very rapid communication it often happens that many countries realize at about the same time that there is an opportunity to do something, or that new techniques are available which make it possible, and that is what has happened basically with continental scientific drilling.

Many technically advanced countries have suddenly seen the need for this in terms of learning about the third dimension of the continental crust, and understanding the processes that shape and form the crust, and unraveling the long history that Jim Papike talked about, and they see it also as a resource frontier both for energy resources and for metallic mineral resources.

In addition to that, I suppose all scientists have a sort of an adventurous streak in them, and I like to call that the Columbus syndrome. We all like to go to some new place and find something

nobody has ever seen before, and getting deeper into the crust than has ever been possible offers such an opportunity.

As a result of these scientific and resource considerations, the U.S.S.R. set up a very large and comprehensive program. That has been followed by France, Belgium, Great Britain, Sweden, Czechoslovakia, the United States, and plans are underway in the Federal Republic of Germany, Japan, Australia, and Canada to initiate such programs. So it is a widespread international effort that is going on.

It is probably instructive to look for just a moment at what some of these other people have found out, because it may guide us a little in developing our programs.

The U.S.S.R. is certainly the prime model. It has a program that contemplates drilling in excess of 10 scientific wells in different parts of the Union. The most notable is the Cola Hole which has already been mentioned that is down on the order of something like 12.5 kilometers, or about 40,000 feet, or nearly 2 miles deeper than the deepest well drilled in the United States, which is the second-deepest well in the world, Bertha-Rogers.

The Russian well is in extreme northwestern Russia close to the Norwegian boundary in the Soviet arctic, and unlike the very deep wells in the United States it drilled into ancient crystalline rocks. So it has been very, very deep into the ancient parts of the crust. They have found several exciting things that lead us to believe that there are many more things down there to be discovered.

For one thing, it had been rather widely assumed that under the enormous pressures at great depth there could not be any open spaces present anymore, and therefore fluids would not be circulating—things like oil, gas, brines, and that kind of thing. The Russians have found that even at in excess of 12,000 meters there are fluids circulating. So it opens up the possibility of valuable liquid resources at these great depths.

They have also found that that well provided a very interesting test of calibrating seismic data because certain seismic reflecting horizons had been defined in that area previous to drilling, and when those horizons were drilled through there was nothing there lithologically in the rock that could be identified as producing the reflecting horizon which opens up a whole lot of problems we need to explore if we are going to use seismic technology to really help us with the deeper parts of the crust, which we have to do because that is the way to get broad coverage, and the drill just makes specific tests to help you understand it.

Finally, they found that in terms of the thermal gradient which is what produces geothermal energy for us, it started out at about 1 degree Centigrade increase per 300 feet that they went down, and then at 10,000 feet it abruptly increased to about 2.5 degrees per 300 feet. So that there was a rapid change toward higher heat production, and that tells us there is just a great deal we do not know about how heat is produced and distributed in the Earth's crust, and therefore there is some opportunity here to see if we can find another kind of energy resources and understand it properly. This would get to the basic science that underlies that.

Now the Russians have their program continuing at a very strong and high level, and they have been quite open in discussing

it with us. Some of us were lucky enough to go over and visit that Cola deep hole, and the Russians told us as far as we could tell, very freely exactly what they were doing, what kind of problems they were having, and what technology they were developing in order to overcome those.

So this seems to me an area in which scientific cooperation with the Russians may be quite feasible, and I think it is good to have that door open as much as possible. In fact, I have just received a communication from the Russian Minister of Geology inviting us to have a conference there in 1988 on continental drilling at which they would share more of their information.

Another program that is just getting into gear is that of the Federal Republic of Germany, and it is quite different from the Russian's, so I will cite it, too. It is to drill one single very deep hole to understand as much as possible the deep crust in central Europe. It is a large, well-organized program operating through an agency called KTB, and since my German is not good, I will not tell you what that means and we will just talk about the KTB.

Senator WARNER. Excuse me. Could you advise me, as an absolute layman on the subject, what are the diameters of these various holes?

Dr. STEHLI. If you try to visualize it in scale, it is just a very, very tiny hole, because it starts out perhaps at 2 or 3 feet in diameter so they can get the necessary casing in place, and then the part that really goes down deep in the Russian hole for instance is only about 8¾ inches in diameter.

Senator WARNER. Did you say 8¾ inches?

Dr. STEHLI. Yes. That is why it is so important to have geophysical tools you can lower down the hole and see a large volume of rock, instead of just that little 8¾-inch piece that you bring up.

At any rate, the Germans are proceeding with a well-organized and very well-funded program, and I think ultimately that is the secret, that these are well-organized, well-funded programs in both Germany and Russia, and that they operate through a single agency, and therefore they can have a well-focused, coordinated program. I believe there is a lesson for us in that as we try to develop a program which results from the efforts of three different agencies.

It is going to take some skill to coordinate those in a way so that it really works very well. I believe we must do that. I think it is important not only for the operation of the program, but because eventually I see that this will go the same way as the ocean drilling and will have good international cooperation in this kind of thing. It means that an experiment might be better done in Borneo or somewhere than in the United States, and in order for us to get the cooperation that would allow that, we have to be able to speak with a single voice in the negotiations that would take place.

I think unless there are some questions, that is all I need to say about international things.

[The prepared statement of Dr. Stehli follows:]

STATEMENT OF

DR. FRANCIS G. STEHLI

Chairman, Coordinating Committee #4 (Continental Drilling
of the International Commission on the Lithosphere)
and
Chairman, Science Advisory Committee of
Deep Observation and Sampling of the Earth's
Continental Crust, Inc. (DOSECC)

Regarding

"THE CONTINENTAL SCIENTIFIC DRILLING
AND EXPLORATION ACT", (S. 1026)

Submitted to the

Subcommittee on Natural Resources Development and Production

of the

Senate Committee on Energy and Natural Resources

July 24, 1986

Mr. Chairman and Members of the Subcommittee:

Continental Scientific Drilling programs have been implemented in several technologically advanced nations at more or less the same time as it became clear to each nation that exploring the third, or depth, dimension of the continents on which we live to unravel their history and to understand the processes that generate and shape them, constitute the next scientific frontier in the earth sciences. They understand too, that exploration of the earth's crust is the frontier for discovery of mineral and energy resources, indigenous supplies of which every country must discover and maintain as a matter of national security. As a result of these scientific, economic and security needs, Continental Scientific Drilling Programs exist in the USSR, France, Great Britain, Sweden, Belgium, Czechoslovakia and the United States. Programs are currently being discussed or planned in Germany, Japan, Australia and Canada.

It is instructive to consider briefly one or two of these national scientific drilling programs and to compare them with the United States' program. The most extensive and ambitious program is that of the USSR, where a series of 10 or more scientific holes was planned during the 1960's. The most celebrated of the Russian holes, and the deepest exploration of the crust anywhere to date, is that at Zapoliarny, northwest of Murmansk in the Kola Peninsula of Arctic European Russia, only a few miles from the Norwegian border.

The Kola hole was begun in 1970 in a nickel-copper mining district, and has been gradually deepened to more than 40,000 feet, almost two miles deeper than the next deepest well in the world, which is the Bertha Rogers #1 in Oklahoma. The Kola hole discovered new ore reserves, allowed development of unique drilling technology, and produced at least three very interesting scientific surprises. First, it was found that, contrary to expectation, the rocks encountered at great depths had numerous open and connected pore spaces which contained and produced fluids. This suggests that fluid natural resources, such as oil, gas, and water, may exist at greater depths than formerly believed. Second, it was found that major seismic discontinuities reported before drilling could not be equated to changes in the rocks, thus indicating that careful comparisons of seismic and drilling results will be essential to any deep exploration of the crust. Third, the thermal gradient, the usually regular increase in temperature with depth which had an assumed value of $1^{\circ}C/300'$ for the first 10,000', thereafter abruptly changed to $2.5^{\circ}C/300'$, so that at about 40,000' the temperature was not the anticipated $120^{\circ}C$ but was over $200^{\circ}C$. Clearly, much remains to be learned about the production and flow of heat in the crust.

The Russians allowed a number of us to visit the Kola hole in 1984 and were very open in discussions of their successes, problems and discoveries. An invitation has recently been extended by the Minister of Geology of the USSR, Mr. Kozlovsky, to hold a Workshop on Continental Scientific Drilling in the USSR in September or October of 1988. Thus, the field of scientific drilling is one that

may provide a vehicle for scientific dialog with the USSR. The Russian program also currently involves drilling a deep well at Saatly near Baku on the Caspian Sea, and another at a location in the Ural Mountains. There is much to learn from this advanced program.

A second program with which we are in very close contact is that of the Federal Republic of Germany, operated by a group called KTB. The German program is concentrated on the drilling of a hole to depths of between 10 km (32,500') and 14.5 km (46,000') for purposes of scientific investigation of the continental crust of central Europe. A decision between two possible sites, one in the Black Forest and one in Bavaria, will be made in September. This effort is large, well-organized and well-financed. The KTB is already at work on new drilling technology which will be valuable to U.S. scientific drilling and could have spin-offs for the beleaguered drilling industry in the U.S.

In contrast with these two programs, that of the U.S. is more diverse. First, from the scientific point of view, we are convinced that many scientifically exciting targets lie relatively close to the surface in dynamic parts of the crust where, at the present time, we can study the processes of crust formation and modification in progress. These shallow but dynamic targets are not easy to study, because high temperatures, high states of stress, and chemically corrosive fluids tend to be associated with them. However, they are places where much can be learned scientifically, and where energy or other resources encountered may be exploitable.

Along with the Russians, Germans, and others, we believe that great gains in new knowledge and technology will also flow from deep holes though they demand considerable new technology before the first ultradeep hole in the U.S. is attempted. We would not contemplate, for instance, drilling for 15 years as the Russians have done at the Kola site. It is our proposal that development and testing should be done at shallower depths before a deep hole is undertaken so that once deep drilling begins, it will progress rapidly to its conclusion.

Secondly, both the Russian and the German efforts are large-scale programs mounted by single government agencies and, thus, they have a high level of focus and internal coherence. By contrast, the U.S. effort is diffuse, with portions of it falling within NSF, USGS, and DOE, with none being large enough or sufficiently well-funded to mount a very aggressive program. One of the lessons we learn from observing other nations' programs is that it is essential to work towards a single, well-coordinated national program that will allow the most effective use of available resources for the benefit of the nation and the agencies involved. Further, it should be recognized that continental scientific drilling may eventually become an international program, with drilling taking place at locations chosen not because they lie within the territory of any nation, but because they represent the very best place in the world to conduct a particular experiment. A U.S. National Program should be designed to take advantage of such an eventuality. This requires a coordinated and coherent program that can speak with a single voice to potential international research partners.

Senator WARNER. Thank you very much.
We will now hear from Dr. Fisher.

STATEMENT OF DR. WILLIAM L. FISHER, DIRECTOR, BUREAU OF ECONOMIC GEOLOGY, AND CHAIRMAN OF THE DEPARTMENT OF GEOLOGICAL SCIENCES, UNIVERSITY OF TEXAS AT AUSTIN

Dr. FISHER. Thank you, Mr. Chairman.

I appreciate the opportunity to testify in support of the program that is authorized in S. 1026. I will summarize very briefly comments that I have set forth in a written statement.

The program of scientific deep drilling as set forth in this bill I think addresses the important need to extend our understanding of the Earth's continents and processes that control and continue to control our geologic environment, the kinds of scientific and engineering research initiatives that can be carried out as a part of a program of this sort involving intermediate depth drilling as well as some very selected deep borings into the roots of the continents.

I would want to emphasize that this is of direct interest to the States and I think would be of substantial interest to the energy and mineral industries in the United States, and indeed throughout the world.

This kind of drilling of course is expensive, but it is a final and it is a definitive test of the predictions and models that we have made in the more shallow subsurface by geologists and by geophysicists.

With the ultradeep drilling we will be able to sample, to test, and to analyze continent-forming processes below the depths which are customarily pursued by the industry in the exploration of energy and mineral resource deposits.

I think deep drilling will give us some very important insights into the growth and development of major oil and gas basins throughout the world. It will be important in those basins leading to the origin of metalliferous solutions, and these points have been made before, and finally, in the origin and maturation of hydrocarbons, in the safe isolation of toxic waste, that whole realm that we deal with in the subsurface is critical and the ability to drill, giving us the three-dimensional view of the Earth, is necessary to understand these processes and will be very, very important to it.

We have over the last 100 years or so, primarily from the petroleum and the mineral industry, developed some fairly sophisticated models. We know the geometry quite well of the subsurface down to the depths that are normally pursued in the exploration of those materials.

Beyond is really a sparsely known frontier, less probed than many parts of outer space, but it is critical to the kinds of processes that shape the important ones in the shallow subsurface that we work with.

I would like to make one last point about a program that should not be overlooked in a program of this size. That is, to demonstrate some fairly substantial benefits of major joint venture research. I think the ultradeep bore holes of the kind that have been proposed offer some very excellent examples of research opportunities that merge the interests and the capabilities of the Government, of in-

dustry, and of the research-oriented universities of the United States.

Industry will participate in return for gains in knowledge and technology. Government will assume part of the cost to reach beyond existing scientific and technological barriers, and that is very much a part of their basic missions.

And I think the third partner in such cooperative ventures, the university, can provide a pool of current knowledge and experience which will be essential for the realization of some very true innovation and scientific progress.

So I think in this kind of joint picturing of these components we bring the essential skills and resources to a national endeavor that will be of very lasting benefit.

I think just as surely as outer space affects our environment at the surface of the Earth, the deeper interior of the Earth affects the shallow subsurface that we probe for water, for minerals, for energy, and for the safe isolation of industrial and toxic waste. I think this Nation needs this kind of a major initiative and, Mr. Chairman, I respectfully ask the subcommittee's support for the bill. Thank you very much.

[The prepared statement of Dr. Fisher follows:]

Testimony on S.1026

A Bill to Authorize

A CONTINENTAL SCIENTIFIC DEEP-DRILLING PROGRAM

U.S. Senate Energy and Natural Resources Committee

Subcommittee on Energy Development and Production

Mr. Chairman and Members:

I am William L. Fisher. I serve as the Director of the Bureau of Economic Geology and the Chairman of the Department of Geological Sciences, both at The University of Texas at Austin. I appreciate the opportunity to testify in support of the program authorized in S.1026.

The program of scientific deep drilling set forth in S.1026 addresses the important need to extend our understanding of the origin of the Earth's continents and the processes that control and continue to change our geologic environment. The results of new scientific and engineering research initiatives carried out as part of regional, intermediate-depth drilling programs, along with carefully sited deep borings into the roots of the continent, are of direct interest to the states and to the energy and mineral industry.

Drilling, although expensive, is the final and definitive test of the predictions and models of the subsurface made by geologists and geophysicists. We probe the greater depths of this planet as we probe outer space. Ultradeep drilling extends our ability to sample, to test, and to analyze continent-forming processes beyond the depths

customarily pursued by industry in the exploration of energy and mineral resource deposits. Deep drilling supports exploration of new frontiers of knowledge and will yield valuable insights into the characteristics of rock-forming processes, the growth and development of major oil-and-gas-bearing provinces such as the Gulf of Mexico basin, the origin of metalliferous solutions in the deep subsurface, and the origin and maturation of hydrocarbons. Literally, the drill is the only means for obtaining the direct three-dimensional view of the Earth necessary to understand the fundamental Earth processes that have led to the origin of continents and the formation of energy and mineral resources.

Deep drilling is a logical and appropriate initiative that effectively builds upon what industry has already accomplished in developing depositional and structural models of the shallow crust. For example, the work of the petroleum industry over the past 100 years has resulted in a highly detailed data base and three-dimensional model of the shallow subsurface in the western Gulf of Mexico. Through drilling, geophysical logging of boreholes, and analysis by several generations of geologists we now generally understand the distribution and geometry of reservoir rocks down to depths of 10,000 to 15,000 feet. Beyond is a sparsely known frontier.

The DOSECC Scientific Advisory Committee is currently reviewing a proposal by scientists to drill an ultradeep borehole to 40,000 feet on the San Marcos Arch in the

western Gulf of Mexico under the auspices of the Continental Scientific Deep-Drilling Program. Projects of this magnitude located in areas where, by scientific consensus, the geologic conditions are well known at intermediate depths and optimum for greatly extending our knowledge of crustal processes, afford an unprecedented opportunity to demonstrate the best of our current technology and to make major gains in knowledge. The conceptual models developed from such extension of knowledge of the deeper crust encourage more accurate prediction and analysis of the magnitude, character, geometry, and distribution of basic Earth process effects and their role in the development of mineral resources.

Of equal importance to Texas and the Gulf Coast in general will be the new knowledge derived from this program that can be applied to major regional issues of fluid waste injection in the subsurface. Each year more than 3 billion gallons of liquid waste products are injected into the subsurface in Texas alone as part of industrial waste disposal activities. The new information that a Continental Scientific Deep-Drilling Program would generate from projects like the San Marcos deep borehole will greatly aid our ability to model waste containment in the subsurface under elevated temperature and pressure conditions. Further, the commitment by government and industry to develop and preserve a deep borehole as a continuing research activity will allow scientists to evaluate subsurface processes over time and under controlled experimental conditions. The ability to establish a

time series for the many physical and chemical processes that can be sampled and measured at great depth ensures that all scientific and engineering users will have ample opportunity to develop new research activities at a controlled, national research site and to build the detailed data bases necessary to address pressing public issues such as waste management.

A last point I would make is that the Continental Scientific Deep-Drilling Program provides a national stage to demonstrate the substantial benefits of major joint venture research. The ultradeep boreholes proposed for the Gulf Coast, the northern Midcontinent, and the East Coast are excellent examples of research opportunities that merge the interests and capabilities of government, industry, and the research-oriented universities of our nation. Industry participates in return for gains in knowledge and technology, and government assumes part of the cost to reach beyond existing scientific and technological boundaries. The third partner in such cooperative ventures, the university scientific and engineering community, provides a pool of current knowledge and experience essential for the realization of true innovation and scientific progress. Thus each party brings essential skills and resources to a national endeavor of great scope and lasting national benefit.

The pursuit of the deep Earth is a program whose time has come. The Russians and the Germans are well along in that pursuit. As outer space affects our environment at the

surface of the Earth, the deeper interior of the Earth affects the shallow subsurface that we probe for water, for minerals and energy, and for the safe isolation of wastes.

This nation needs this major initiative, and I respectfully ask the Subcommittee's support for S.1026.

Senator WARNER. Thank you very much, Doctor.

I note, Dr. Fisher, that you were an Assistant Secretary of the Department of the Interior——

Dr. FISHER. That is right, sir.

Senator WARNER [continuing]. Dealing with this subject a number of years ago.

Dr. FISHER. Thank you, sir.

Senator WARNER. We will now have Dr. Carel Otte, UNOCAL.

STATEMENT OF DR. CAREL OTTE, PRESIDENT, UNOCAL GEOTHERMAL DIVISION, UNOCAL CORP.

Dr. OTTE. Mr. Chairman, my name is Carel Otte and I am President of the Geothermal Division of the UNOCAL Corp., and I have a prepared statement that I will submit for the record here and, likewise like the other speakers, I would like to summarize my statement for you and paraphrase it.

UNOCAL is one of the leading companies. We are one of the pioneering companies in geothermal energy, and we have been engaged in developing this resource now for about 25 years. Having been associated with this development from its very beginning, I believe that as an industry spokesman I personally am appreciative of the factors that are standing in the way of faster growth of this industry.

Now some of these factors are associated with an inadequate understanding of the Earth's continental crust, but also specifically with the origin and the occurrence of geothermal resources. So for this reason alone, industry will endorse and should endorse the R&D aspects of the Continental Scientific Drilling Program for the development of new concepts, and to study the processes as they have evolved over time and affected the chemical and the physical properties of our continental crust.

Perhaps not as well known to my scientific colleagues here, I can assure you that the results that were forthcoming from the Ocean Drilling Program have had a revolutionary impact upon the hydrocarbon research that has been taking place by the various oil companies. They traditionally have to study sedimentary basins, and they piece together the geologic history of these sedimentary basins as they occurred. And the revolutionary outcome of the results of the Deep Ocean Drilling Program has had indeed tremendous impact upon the thinking of the petroleum companies.

It is likewise that we feel that the science that would be forthcoming, the new concepts and confirmation of current theories and processes, would likewise have an additional revolutionary impact on the discovery and the exploration of new mineral resources, not only hydrocarbon, but geothermal and also ore minerals.

However, I am here also for one other reason. That is, a technology reason. In the search for geothermal resources the industry has originally taken the oil drilling techniques that were developed by the petroleum industry and the service companies and have further modified them and perfected them so that they could drill for geothermal resources into the Earth's crust. By doing so, we have made incremental improvements in both the technology and the instruments, and some of the systems: better material development,

elastomers, cements, drilling muds, drilling tools. But we are now up against the current limits that we have encountered that are approximately 350 degrees Centigrade, or roughly 650 degrees Fahrenheit. That is about what the drilling tools can withstand.

It is the industry's belief that the ultradeep drilling that is contemplated in the Continental Scientific Drilling Program will ultimately also be limited by the same limitations that the geothermal industry has, because the conditions that they are going to encounter will be conditions of high temperature, hard rock, pressures, fluid pressures and rock pressures deviating from normal, corrosive conditions, et cetera, the same limitations that we have encountered in geothermal systems in shallower portions and positions of the Earth's crust.

It is for this reason that the industry strongly endorses this particular program with the additional recommendation that parallel and simultaneous with the embarking on this particular deep drilling program there is a research and development program launched to work cooperatively with Federal Government agencies like some of the national laboratories and industry to further develop drilling technology and drilling systems to allow us to drill deeper.

You may ask yourself, you heard from a previous witness, Dr. Stehli here, Professor Stehli, about what the Russians are doing. Many years ago the Russians embarked on the development of an entirely different drilling system than basically was developed by the petroleum industry. Although in the beginning they struggled with it and they were not capable of drilling as deeply as we were in the petroleum industry, they ultimately by stepping backward have been able to go forward.

I think we will have hard times by our conventional rotary drilling tools to, for instance, achieve a depth of about 40,000 feet. We will probably have to maybe take a look and step backward. In any event, I believe that the technological outfall of a program like this will be of incredible importance to the United States. Because while I am sitting here, and although we are faced with an oil glut and the press reports it every day, I would venture to say that 10 years from now, and just recently I read an article by Dr. Fisher here in the Association of American Petroleum Geologists Bulletin, and I think he will endorse it, come 10 years from now, certainly 15 years from now, we will be right back in the same shortages again.

The petroleum industry will be asked to find new resources for this society and for the security of our Nation, and we will be exploring in the deeper regions of the existing sedimentary basins and other portions of the continental crust, and we will need those tools.

It is for this reason that I urge you to consider this program, and I urge you also to endorse the concept of further technology development.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Otte follows:]

STATEMENT OF DR. CAREL OTTE

PRESIDENT, UNOCAL GEOTHERMAL DIVISION

UNOCAL CORPORATION

BEFORE THE

SUBCOMMITTEE ON NATURAL RESOURCES AND PRODUCTION

OF THE

SENATE COMMITTEE ON ENERGY AND NATURAL RESOURCES

JULY 24, 1986

MR. CHAIRMAN AND MEMBERS OF THE SUBCOMMITTEE, I AM CAREL OTTE, AND AM PRESIDENT OF UNOCAL GEOTHERMAL DIVISION, UNOCAL CORPORATION. UNOCAL HAS BEEN ENGAGED IN THE EXPLORATION AND PRODUCTION OF GEOTHERMAL RESOURCES FOR ALMOST 25 YEARS. WE ARE CONSIDERED ONE OF THE PIONEER DEVELOPERS OF THIS NEW ENERGY RESOURCE AND WE ARE THE WORLD'S LEADING PRODUCER. I HAVE BEEN IN CHARGE OF OUR COMPANY'S GEOTHERMAL WORK FROM THE ORIGINAL PIONEERING DAYS AND I HAVE HAD A CLOSE INVOLVEMENT IN BUILDING THIS NEW RESOURCE INDUSTRY. I BELIEVE THAT I HAVE A GOOD APPRECIATION OF THE FACTORS THAT ARE STANDING IN THE WAY OF FASTER GROWTH. SOME OF THESE FACTORS ARE ASSOCIATED WITH INADEQUATE UNDERSTANDING OF THE ORIGIN AND OCCURRENCE OF GEOTHERMAL RESOURCES. FOR THIS REASON, I WHOLEHEARTEDLY SUPPORT THE GOALS OF THE CONTINENTAL SCIENTIFIC DRILLING PROGRAM. I FIRMLY BELIEVE THAT THIS LEGISLATION IS ESSENTIAL TO ACHIEVING A BETTER BASIC UNDERSTANDING OF THE EARTH'S PROCESSES THAT OPERATED OVER THE LAST FOUR BILLION YEARS AND THAT HAVE LED TO THE PRESENT CHEMICAL AND PHYSICAL STRUCTURE OF THE EARTH'S CONTINENTAL CRUST. I FURTHER BELIEVE THAT THIS LEGISLATION IS ESSENTIAL FOR THE CONTINENTAL SCIENTIFIC DRILLING EFFORT TO ACHIEVE THESE GOALS.

AS AN EARTH SCIENTIST THAT HAS WORKED HIS ENTIRE PROFESSIONAL LIFE IN INDUSTRY EXPLORING FOR ENERGY RESOURCES, FIRST HYDROCARBON AND LATER GEOTHERMAL, I AM FIRMLY CONVINCED THAT ARMED WITH BETTER KNOWLEDGE OF OUR CONTINENTAL CRUST, INDUSTRY

CAN DO A BETTER JOB IN ENSURING THAT ADEQUATE SUPPLIES OF ENERGY AND MINERAL RESOURCES BE AVAILABLE IN THE FUTURE TO SUSTAIN MANKIND. LIKE THE CONCEPT OF PLATE TECTONICS, THAT EVOLVED FROM THE OCEAN DRILLING PROGRAM TWENTY YEARS AGO AND THAT HAD A REVOLUTIONARY IMPACT ON THE EXPLORATION FOR HYDROCARBON DEPOSITS, LIKEWISE, I BELIEVE THAT THE CONTINENTAL SCIENTIFIC DRILLING PROGRAM WILL PRODUCE KNOWLEDGE THAT WILL FURTHER REVOLUTIONIZE OUR EXPLORATION FOR ALL TYPES OF MINERAL RESOURCES.

HOWEVER, THERE IS ANOTHER REASON THAT INDUSTRY SUPPORTS THIS PROGRAM, AND THAT IS PURELY TECHNOLOGICAL. WE ARE HOPEFUL THAT IMPLEMENTATION OF THIS DEEP SCIENTIFIC DRILLING PROGRAM WILL LEAD TO THE DEVELOPMENT OF IMPROVED DRILLING TECHNIQUES, BETTER OR NEW DRILLING AND LOGGING INSTRUMENTS AND TOOLS, PERHAPS WHOLE NEW DRILLING SYSTEMS. TEN YEARS HENCE, MAYBE SOONER, INDUSTRY NEEDS THOSE IMPROVED TOOLS AND TECHNIQUES IF IT IS TO CARRY OUT ITS TASK OF DELINEATING THE NEEDED ENERGY SUPPLIES FOR THE NATION. THEY WILL BE LOOKED FOR IN THE DEEPER REGIONS OF THE EXISTING SEDIMENTARY BASINS, OR IN DEEPER THERMAL AREAS FOR GEOTHERMAL RESOURCES WHERE EXISTING TOOLS AND TECHNIQUES ARE INADEQUATE OR ARE BEING PRESSED TO THE LIMIT.

EARLIER I STATED THAT MY COMPANY WAS ONE OF THE EARLY PIONEERS IN THE INDUSTRY AND THAT IT IS THE WORLD'S FOREMOST PRODUCER OF

GEOTHERMAL ENERGY. IN FACT, UNOCAL HAS DRILLED OVER 650 WELLS WORLDWIDE IN THE EXPLORATION AND DEVELOPMENT OF GEOTHERMAL RESOURCES AND THAT IS IN THE TOUGHEST DRILLING ENVIRONMENT WE HAVE EVER ENCOUNTERED. THE GEOLOGICAL CONDITIONS FOR GEOTHERMAL ENVIRONMENTS ARE VERY HOSTILE. THE ROCKS ARE HARD AND TOUGH TO DRILL, THE TEMPERATURES ARE HIGH FOR THE DRILLING SYSTEMS THAT WE USE. FREQUENTLY WE ENCOUNTER FLUID AND ROCK PRESSURES DEVIATING FROM NORMAL AND FLUID CONDITIONS THAT ARE VERY CORROSIVE. OVER THE YEARS THE GEOTHERMAL INDUSTRY HAS MADE STEADY ADVANCES IN DRILLING PRACTICES WHICH HAD THEIR START FROM THE PETROLEUM INDUSTRY, AND WE ARE PROUD OF OUR ACCOMPLISHMENTS. THESE ADVANCES HAVE ALLOWED US TO DRILL INTO 350 DEGREES CENTIGRADE (662 DEGREES FARENHEIT) ROCKS OVER FOUR KILOMETERS DEEP (13,000 FEET). THE COMBINED COOPERATIVE RESEARCH EFFORT OF INDUSTRY AND GOVERNMENT WAS NEEDED TO ACHIEVE THIS SUCCESS.

BUT IN GEOTHERMAL, WE ARE CURRENTLY OPERATING AT THE EXTREME LIMIT OF HIGH TEMPERATURE DRILLING TECHNOLOGY. AS WITH ANY TECHNOLOGY OPERATED AT THE LIMIT OF ITS CAPABILITY, WE HAVE SERIOUS OPERATING AND RELIABILITY PROBLEMS WHICH RESULT IN GEOTHERMAL DRILLING COSTING AS MUCH AS FOUR TIMES PER FOOT OF HOLE THAN OIL AND GAS DRILLING TO EQUIVALENT DEPTH.

NOW THE PROGNOSIS IS THAT THE ULTRA-DEEP DRILLING IN EXCESS OF 30,000 FEET ENVISIONED WITH THE CONTINENTAL SCIENTIFIC DRILLING

PROGRAM WILL ENCOUNTER CONDITIONS SIMILAR TO THOSE ASSOCIATED WITH GEOTHERMAL ENERGY SYSTEMS AND SIMILARLY MAY BE LIMITED BY TECHNOLOGY.

FOR THESE REASONS THE GEOTHERMAL INDUSTRY STRONGLY URGES THAT WITH ADOPTION OF THE CONTINENTAL SCIENTIFIC DRILLING PROGRAM A PARALLEL RESEARCH EFFORT BE LAUNCHED TO IMPROVE EXISTING DRILLING TOOLS, TECHNIQUES AND LOGGING AND SAMPLING INSTRUMENTS; PERHAPS EVEN CONSIDER ENTIRE NEW DRILLING SYSTEMS. THIS PROGRAM SHOULD BE AN INTEGRAL PART OF THIS CONTINENTAL SCIENTIFIC DRILLING PROGRAM AND I STRONGLY URGE THAT THIS BE A JOINT PROGRAM BETWEEN GOVERNMENT AND INDUSTRY.

DEVELOPMENT OF IMPROVED DRILLING AND LOGGING TOOLS AND TECHNIQUES CAPABLE OF DRILLING ULTRA DEEP, HIGH TEMPERATURE HOLES WILL NOT ONLY ASSIST CONTINENTAL SCIENTIFIC DRILLING PROGRAM IN ACHIEVING ITS GOALS, IT WILL BE OF GREAT BENEFIT TO SOCIETY IN ENABLING INDUSTRY TO UNCOVER AND DEVELOP THE NEEDED NEW GEOTHERMAL ENERGY SUPPLIES AND HYDROCARBON RESOURCES IN THE FUTURE. I HOPE THE COMMITTEE WILL CONSIDER THESE RECOMMENDATIONS WHEN ADOPTING S. 1026. I SHALL BE HAPPY TO ANSWER ANY QUESTIONS YOU HAVE.

THANK YOU VERY MUCH.

Senator WARNER. Thank you, Dr. Otte.

I certainly share the view expressed in your article, Dr. Fisher, and confirmed by you, Dr. Otte, that we have a limited amount of time before we will be confronted, not only this Nation but indeed much of the world, in terms of its energy shortage. I presume, not having read your article, that perhaps you discounted very wisely political military disruptions. You looked at it, I suppose, from a geologic standpoint, but there could easily be other problems to arise to cut that energy down.

Dr. Otte, you are associated with one of the most distinguished private-sector institutions. I wonder what sharing of information flows as a consequence of the limited R&D done by the private sector in this area? We are talking here today about a program where there would be a complete freedom of information and sharing of information, but what takes place in the private sector? First, the quantum of R&D; and, second, the exchange of the information.

Dr. OTTE. Senator Warner, I would say from the standpoint of technological advances particularly in the drilling technology, the exchange is very wide and is very immediate. In the United States the bulk of the drilling technology is in the hands of service companies, and they have to disseminate that knowledge in their tools and sell them. They not only sell them in the United States, they sell them abroad. Although the bulk of the resources, hydrocarbon resources for instance, are currently produced abroad in the Middle East as you well know, much of the industry that develops it is still American based.

Incidentally, and this is a personal caveat, this is what concerns me so deeply about the current state of the energy industry, because it is the service companies that are currently leaving the business and have to cut back, and with it we lose our technological base.

But in any event, the sharing of the information is very widespread as to the technology development, the instrumental development, something that you can hold in your hand to do a job with. In fact, it is also international and it is very widespread in exchange.

What is necessary, and this is why I am urging a cooperative effort from industry and the private sector, there is much technology currently in the laboratories of the service companies and the industry. If some measure of patent protection can be given to a person who has a novel idea, or a company, and that shares it, and that accepts Federal funding in order to further development, this is for instance the Japanese who are very adept at this, and this is the one impediment that has existed in the past, that a company by accepting maybe a Federal contribution thereby lost control of his patents, et cetera.

But if we can provide additional protection so that a person at least, because he was the early bird, can capitalize on this, then we will see very many advances. The reason I propose a cooperative Federal/industry-sponsored program is that there is so much knowledge currently in the industry—also, the knowledge of what not to do, of what has not worked—that I think we can make faster

progress if we combine the two forces. I think we will prevent the reinventing of the wheel type of a concept.

Senator WARNER. Thank you, Doctor.

Dr. OTTE. Currently there are joint projects underway between Government and private industry in the national labs, Sandia, for instance, in Albuquerque.

Thank you, Senator.

Senator WARNER. Thank you, Doctor.

The Chair will continue this hearing but suggests that we take a 5-minute break. We will start just before 11:45 with the next panel. That gives everybody an opportunity to have, in the good old baseball tradition, a seventh-inning stretch.

Thank you very much.

[Recess.]

Senator WARNER. Thank you, gentlemen.

I notice the absence of any ladies today as witnesses. Is this a field that precludes such participation?

All right, Dr. Costain, I think you lead off according to our schedule.

STATEMENT OF DR. JOHN K. COSTAIN, PROFESSOR OF GEOPHYSICS, DEPARTMENT OF GEOLOGICAL SCIENCES, VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Dr. COSTAIN. Thank you, Senator Warner.

My name is John Costain, professor of geophysics at Virginia Tech, and I would like to summarize my written testimony in about 5 minutes.

Senator WARNER. Thank you, sir.

Dr. COSTAIN. But I request that the written testimony be included for the record.

Senator WARNER. Yes. All testimony submitted will be included in full in the record.

Dr. COSTAIN. My purpose here is to indicate strong support of the proposed Continental Scientific Drilling Program. In discussing the merits of an ultradeep drilling program I will refer to a specific project in this program and elaborate on two scientific objectives that I feel play an important part in ultradeep drilling.

The project to which I refer is called ADCOH, A-D-C-O-H, standing for Appalachian ultradeep core hole, a project for an ultradeep hole in the southern Appalachians now in the site-selection phase, and endorsed in 1984 by the Continental Scientific Drilling Committee of the National Academy of Sciences as the project that should be undertaken first in the Continental Scientific Drilling Program.

Plate tectonics is now taught in every elementary course in the geological sciences. Drilling played a critical role in this scientific advance. Although the theory of plate tectonics is generally accepted, we lack a complete understanding of why, how, and what happens when two plates collide.

The edge effects that result from a collision are impressive. One example of an edge effect at a plate boundary after plate collisions is the Appalachian Mountain System. One of the consequences of colliding plates is the formation of immense thin sheets of crustal

rocks that are shoved over themselves. We call these structures thrust sheets, and they have been recognized in all major mountain chains in the world.

The Blue Ridge-Piedmont thrust sheet in the Appalachians represents one of the largest intact thrust sheets in the world. But plates do not only collide; they also split in two to form oceans such as the Atlantic Ocean. When they split, faults and fractures are formed in the crust to depths of at least 10 to 20 kilometers. Reflection seismology can tell us about the very large faults in the crust that have been used over and over again as plates have collided and then split apart. Only the drill can tell us about water-filled fractures that extend to depths of 20 to 25 kilometers. If we wish to understand earthquakes, we must understand how water is transmitted in a fractured crust.

No major technological breakthroughs are required in order to complete the ADCOH 10-kilometer core hole. In the relatively benign physical environment of 200 degrees Centigrade of the eastern United States, only modification of available coring technology, careful mechanical design of the hole, and modification of available equipment are necessary.

I choose two specific scientific justifications for a deep drilling program.

The first is to test the ideas generated from interpretations of reflection seismology data. Such data from the ADCOH site study are included as figure 1, much reduced in scale from my testimony, and I hope you have the correct version of that, but it is the last page.

This is our data base. The dark horizontal lines at about 3 seconds represent energy reflected back to the surface of the Earth from depths of about 10 kilometers. The ADCOH seismic section shows the major structural feature known as the Blue Ridge-Piedmont thrust sheet referred to earlier. We now have a lot of ideas, such as the thickness and composition of thrust sheets from interpreting reflection seismology data that need testing by drilling. We need to understand how reflections are formed in the crust, and if they are coming from what we think they are.

Second, I wish to emphasize the importance of finding out to what degree the fractures in the Earth's crust are water filled, interconnected, and transmitting ground water at the present time. There is no way other than drilling to accomplish this. Shallow drilling to several thousand feet will not provide a guide to the amount of fracturing at depth.

In the past it was often assumed that water in crystalline rocks at depth was present in small amounts and, because of the low permeability of the rocks, did not move far or rapidly. The Russians' discovery of flowing water in fractures at depths of 11 kilometers is direct and spectacular evidence for fracture permeability at depth.

Indirect evidence is the earthquakes associated with filling of the Aswan Reservoir in Egypt. The hypocenters of the reservoir-induced earthquakes are at depths of 5 to 25 kilometers. These earthquakes are evidence for preexisting fractures already in place at hypocentral depths.

We suggest that larger and deeper earthquakes in the interior of continents, but not near reservoirs, have much in common with the shallower reservoir-induced earthquakes.

A deep hole provides the only means of sampling the fluids present in fractures at great depth. We have proposed a hypothesis termed hydroseismicity at Virginia Tech for earthquakes that do not result from two plates colliding. That is, for earthquakes that occur in the interior of plates. Our hypothesis invokes hydrologic—that is deep regional ground water flow; geologic, faulted, fractured crusts; and chemical, hydrolytic weakening of rocks by the pressure solution of quartz components.

We believe that those earthquakes in the interior of plates are directly related to water in the crust, how much the crust is already fractured to depths of about 20 kilometers, and the effect that water from recharge areas of ground water basins has when it reaches these fluid-filled fracture networks.

We propose correlations between locations of rivers, rainfall, and earthquakes in the interior of plates. We must have direct measurements of fracture permeability, fluid pressure, and fluid pressure changes that can only be obtained by monitoring changes in pore pressure at the depths at which earthquakes occur.

In conclusion, I strongly support the proposed Continental Scientific Drilling Program. We lack a complete understanding of how plates are deformed when they split apart, and how thrust sheets are formed when plates collide. We have reached a point in our interpretation of reflection seismology data when some of our ideas about the thicknesses and compositions of thrust sheets should be tested by ultradeep drilling.

One consequence of the plate interactions is faulting and fracturing of the plates to great depths. Some of these fractures are still open, and we believe they are connected and transmit water. Somehow in the interiors of plates we believe water plays an important role in triggering earthquakes. The ADCOH project will address many of these problems.

Thank you.

[The prepared statement of Dr. Costain follows:]

TESTIMONY BEFORE THE SUBCOMMITTEE ON
NATURAL RESOURCES DEVELOPMENT AND PRODUCTION

In support of S. 1026
Continental Scientific Drilling Program

by

John K. Costain
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Blacksburg, Virginia 24061
July 24, 1986

My purpose here is to indicate strong support of the proposed Continental Scientific Drilling Program. This program will add immensely to our understanding of the processes of formation of continental crust, and provide needed spinoffs in drilling technology. In discussing the general merits of an ultradeep drilling program, I will refer to a specific project in this program and elaborate on two scientific objectives that I feel play an important part in ultradeep drilling. The project to which I refer is called ADCOH (Appalachian UltraDeep COre Hole), a project for an ultradeep hole in the southern Appalachians, now in the Site Selection phase, and endorsed in 1984 by the Continental Scientific Drilling Committee of the National Academy of Sciences as the project that should be undertaken first in a Continental Scientific Drilling Program.

Most studies of the Earth's crust are limited by exposures of rocks provided by nature: stream cuts, mountainsides and coastal exposures. At most, these reveal one to two miles of vertical rock at any one location. Geologists can piece together exposures from different parts of the same area, but we now know that extrapolating these geologic maps even a few thousand feet in some locations cannot be done with confidence. We are limited in our attempts to understand and directly observe the internal structure of the Earth's crust because it averages about 25 miles (40 km) in thickness near coastlines, and in a few areas attains thicknesses of 50 miles (80 km) on the continents. We are correspondingly limited in our ability to understand how that folded and faulted geometry came to be (i. e., how was the crust formed?). For many important physical characteristics of rocks, what we see at or near the surface is not what we get at depth. The ultimate key to understanding the genesis of the continents is through direct sampling of the crust by core drilling.

Drilling into the ocean floor for purely scientific purposes during the past 15 years resulted in tremendous gains in our knowledge of the sea floor and its resources, and of the origins and ages of the ocean basins themselves. The acceptance by the scientific community of plate motions (continental drift) was as significant a revolution for the development of the geological sciences as quantum mechanics was to physics. ***Plate tectonics*** is now taught in every elementary course in the geological sciences. Drilling played a critical role in this scientific advance. On land, industrial exploration for hydrocarbons and minerals has for almost a century depended upon samples obtained from drilling for the ultimate confirmation of hydrocarbons or valuable metals.

Although the theory of plate tectonics is generally accepted, we lack a complete understanding of why, how, and what happens when two plates ***collide***. The *edge effects* that result from a collision are impressive. One example of an edge effect at a plate boundary after plate collisions is the Appalachian Mountain System. One of the consequences of colliding plates is the formation of immense thin sheets of crustal rocks that are shoved over themselves. We call these structures "thrust sheets," and they have been recognized in all major mountain chains in the world. *The "Blue Ridge-Piedmont thrust sheet" in the Appalachians represents one of the largest intact structures of its kind in the world.*

But plates do not only collide; they also **split** in two to form oceans such as the Atlantic Ocean. When they split in two, faults and fractures are formed in the crust to depths of at least 10-20 km (33,000-66,000 feet). I will elaborate below on why these fractures are important to us now. Reflection seismology can tell us about the very large faults in the crust that have been used over and over again as plates have collided and then split apart. *Only the drill can tell us about water-filled fractures that extend to depths of 20-25 km (66,000-82,000 feet). If we wish to understand earthquakes, we must understand how water is transmitted in a fractured crust.*

An ultradeep hole through the Blue Ridge-Piedmont thrust sheet will provide new information about the way mountains and the continental crust are formed as well as provide spinoffs in the study of earthquakes, drilling technology, and mineral/hydrocarbon resources technology. This in turn will help us to understand both the way deposits of minerals and hydrocarbons in mountain chains form and how we can find them more economically.

There are a number of problems in the United States that could be successfully addressed by drilling a deep core hole. A hole started in some of the old crust exposed in Minnesota, or the Adirondack Mountains and drilled to considerable depths, would provide information about the nature of the deeper continental crust. The ultradeep (about 12 km) hole completed by the Russians in the Kola Peninsula of northwestern Russia addresses this problem of drilling a deep hole into old crust.

My testimony in support of a Continental Scientific Deep Drilling Program has for its basis the realization that only the drill can provide the ground truth necessary to launch us into the next level of understanding. No known or foreseeable future technology will replace the drill. This has been acknowledged by the National Academy of Sciences Continental Scientific Drilling Committee (National Academy of Sciences 1979), which in November, 1983, endorsed the southern Appalachians as the prime target area for the first hole in the deep drilling program (Reference: National Academy of Sciences, 1984). The ADCOH Project is more fully described by Hatcher and others (1986) in the primer included as Appendix A to this testimony, as well as in approximately 30 papers that have been given at scientific meetings worldwide reporting on the results to date. Our goal here is to extend the frontiers of knowledge about the Earth's crust to a depth never before achieved in the western world. Consequently, the selection of a place to drill a 10-km (≅33,000 feet) hole must be made carefully.

No major technological breakthroughs are required in order to complete the ADCOH 10-km core hole. In the relatively benign physical environment of the eastern United States, only modification of available coring technology, careful mechanical design of the hole, and modification of available equipment are necessary.

I choose two scientific justifications for a deep drilling program. The written testimony by R. D. Hatcher addresses others.

1. CONFIRMATION OF REFLECTION SEISMOLOGY DATA

The first of my reasons for justifying a scientific drilling program is to test the ideas generated from interpretations of reflection seismology data. Such data (from the ADCOH Site Study) are shown in Figure 1, much

reduced in scale. This is our data base. The dark horizontal lines at about 3 seconds represent energy reflected back to the surface of the Earth from a depth of about 9 km. Many other reflections are evident on this "seismic section"; our goal is to explain each reflector (i. e., do the same reflectors come to the surface tens or hundreds of km away, or have they been encountered at shallower depths by the drill?). Only then can we say that we understand the geology and the internal structure of the crust. The seismic section is a measure of how much and from what depths energy is reflected back from internal structures in the crust.

Confirmation of plate tectonic models of the Earth's crust. The ADCOH seismic section (Figure 1) shows the major structural feature known as the *Blue Ridge-Piedmont thrust*, referred to earlier. We interpret it to be at a depth of about 7 km (arrow) on ADCOH Line 1. Indirect methods of observation, such as reflection seismology, provide us with the best image of the interior of the crust. In fact, much of the confirmation of the shapes of the thrust sheets of the Earth's crust has come from reflection seismology data. The results from reflection seismology published since 1978 have been so remarkable that the time has come to confirm interpretations of these images. We now have a lot of ideas derived from reflection seismology data that need testing by drilling. This will give us insight as we acquire and interpret new reflection seismology data and when we choose sites for ultradeep holes.

An ultradeep scientific hole, because of the costs involved, should serve as a laboratory or standard section for a multitude of site-specific geologic and geophysical calibrations and studies. The pencil of information should become a reference point to reach outward and constrain or guide studies tens or hundreds of miles away. Such extrapolation is done by surface geological studies and subsurface imaging by reflection seismology. The ADCOH Project is the ideal place for this standard section because of the multitude of crustal structures to be penetrated.

The crust is not equally reflective everywhere, however. In those locations where it is, a primary consideration in site selection should be the number and quality of reflectors that will be penetrated by the drill and the geographic extent of these reflectors. Selection of a deep drilling site that does not penetrate reflectors of regional significance restricts the potential contributions of a 10 km hole. If a drill site is selected that will impact our understanding of the genesis of mountains in other parts of the United States, then the entire country benefits from such a program.

2. DEEP FRACTURE PERMEABILITY

I wish to emphasize the importance of finding out to what degree the fractures in the Earth's crust are water-filled, interconnected, and transmitting groundwater at the present time. There is no way other than drilling to accomplish this.

The importance of shallow fractures is acknowledged by all geologists and geophysicists. The local occurrence of uranium ore in the Commonwealth of Virginia occurs in a geologic setting of regional extent, a setting in which fractures and reactivated fault zones such as "ductile deformation zones" play an important role. The Brevard Fault Zone, one of the targets of the ADCOH superdeep hole, was at one time also a ductile deformation zone.

Shallow drilling (several thousand feet) will not provide a guide to the amount of fracturing at depth. Studies of fractures in crystalline rocks in other areas in North America indicate that open fractures that transmit water at a significant rate can be expected. (Fractures that transmit or accept greater than one gallon per minute are arbitrarily defined as fractures that are of regional concern.) The average distance water would travel in 100 years in a fracture zone that transmits water depends, of course, on the degree of openness of the fractures in the zone, and could be tens of miles or tens of feet.

Based on drilling experience in crystalline rocks, the occurrence of open fractures at depths greater than 1800 ft in crystalline rock indicates that the number and void volume of open fractures in general bears no relation to depth, at least for the first few thousand feet, *even though there may be such a relationship observed in a shallow rock fracture zone*. Extensive drilling experience in crystalline rocks in the Piedmont of the southeastern United States has indicated that fractures that transmit water do, in fact, occur deeper and that their presence is not correctly sampled by near-surface drilling.

In the past, it was often assumed that water in crystalline rocks at depth was present in small amounts and, because of the low permeability of the rocks, did not move far or rapidly. The Russians' discovery of flowing

water in fractures at depths of 11 km (Kozlovsky, 1982) is direct and spectacular evidence for fracture permeability at depth. Indirect but equally impressive evidence for in-place fracture permeability deep in the crust are the earthquakes associated with the filling of the Aswan Reservoir in Egypt. On November 14, 1981 a magnitude 5.5 earthquake occurred near the reservoir; this was followed by many aftershocks. The main shock occurred four days after the seasonal maximum in water level in the reservoir. The largest aftershock was of magnitude 4.5 on August 20, 1982, and occurred 8 days after the water level began to increase at a rate of 3-4 cm/day following the seasonal minimum. *The hypocenters of the reservoir-induced aftershocks are at depths of 5-25 km in the crust. These earthquakes are evidence for preexisting fractures already in place at hypocentral depths.* Over 1,000 earthquakes (magnitude $\leq$ 3.2) were recorded over a period of about 7 months that were associated with filling the Jocassee, South Carolina, reservoir, about 30 miles from the ADCOH Site Study. The region was previously considered to be aseismic. We propose that larger and deeper earthquakes in the interior of continents, but not near reservoirs, have much in common with the shallower reservoir-induced earthquakes.

My underlying premise is that shallow exploratory holes cannot adequately define the local ground water regime in fractured crystalline rocks. There is extensive petrologic and experimental evidence for significant and widespread permeability and circulating water in crystalline rocks at great depths. *In areas where crystalline rocks extend to the surface, the pressure in water-filled fractures is probably equal to the hydrostatic pressure to depths of at least 10 km.* This has major implications for petrologists.

Properties of the fluids in the fractures. A deep drill hole provides the only means of sampling directly the fluids present at great depths in the Appalachians. Why do we want to sample fluids? In addition to purely academic reasons, if high-level nuclear waste is to be stored in crystalline rocks, the nature of fluids that might be expected to circulate through these rocks should be known. Direct sampling of fluids from the deep ($\cong$10,500 feet; 3.2 km) hole recently drilled in the Salton Sea has been moderately successful, and technological advances resulting from that endeavor could be applied in the ADCOH hole. Sampling in the ADCOH hole should be considerably less complicated, owing to the lower temperatures expected here as compared to those found in the Salton Sea and the non-caustic environment.

Rock samples from a deep hole can be used for, among other things, a detailed study of "fluid inclusions" in rocks. Although some would argue that the same sampling could be obtained from surface outcrops, there is always some uncertainty concerning the exact vertical relationship between any two samples; and the lateral relationship is totally unknown and usually not even considered.

Why is it important to define temporal and spatial variations in fluid properties? These characteristics are used routinely in the search for various types of ore deposits and geothermal resources. Although the region of the southern Appalachian ADCOH hole is not currently known for its ore deposits, the general physical environment expected at depth is similar to that proposed for the formation of greenstone-hosted gold deposits; and gold has historically been mined from quartz veins throughout the Appalachians.

Core from a deep drill hole is more likely to provide accurate information about the chemical changes in fluids in fluid inclusions in crystalline rocks such as would be encountered in the ADCOH hole. In addition, samples from a deep hole would be less likely to contain the numerous secondary inclusions typical of many metamorphic rocks. These secondary inclusions significantly complicate the interpretation of fluid inclusions from these samples; and their expected absence from deep drill hole samples would, therefore, facilitate data collection and interpretation.

Direct monitoring of pore pressure and pore pressure changes in fractures at hypocentral depths: a possible link with Earthquakes in the eastern United States. We have proposed a hypothesis termed ***Hydroseismicity*** for earthquakes that do *not* result from two plates colliding, i.e., for earthquakes that occur in the interiors of plates, not where plates collide. Our hypothesis invokes hydrologic (deep regional groundwater flow), geologic (faulted, fractured crust), and chemical ("hydrolytic weakening" of rocks by pressure solution of quartz) components. It is important to understand the earthquakes in the interiors of plates as well as those located at major plate boundaries because earthquakes in plate interiors can have very large felt areas. The best examples are the destructive earthquakes at New Madrid (1811-12), Missouri, and Charleston (1860), South Carolina. The 1811-1812 New Madrid earthquakes (magnitudes of 7+) were reported felt in Washington, DC, a distance of about 750 miles. The Charleston earthquake had a magnitude of about 6.8. We believe that those earthquakes

in the interiors of plates are directly related to water in the crust, how much the crust is already fractured to depths of about 20 km, and the effect that water from recharge areas of groundwater basins has when it reaches these fluid-filled fracture networks. We must have direct measurements of fracture permeability, fluid pressure, fluid pressure changes that can only be obtained by drilling to the depths at which earthquakes occur and monitoring changes in pore pressure.

Hydroseismicity has for its basis an observed correlation between 1) those places away from edges of plates where there are many earthquakes, 2) large "gravity-driven" river basins that can provide an adequate supply of water to the upper- and mid-crust, and 3) fractured crust (an in-place fractured, connected, permeable volume). It assumes that the most probable areas for earthquakes are the *intersections* of major river basins with higher fracture permeability in rifted (fractured) crust. Specifically, it is suggested that in crust with a combination of abundant fracturing and more groundwater, as opposed to surface runoff, there will be an increased probability of seismicity. Gravity-driven groundwater basins in the eastern United States occupy large (100-200 km wide X several hundred km in length X ≅ 20 km in depth) volumes of the crust. Groundwater flow within these volumes is 3-dimensional but conceptually simple. We hypothesize that water from recharge areas of groundwater basins is transmitted to depths of 10-20 km in the crystalline upper crust and thereby triggers earthquakes. The model, except for scale, resembles that familiar to groundwater hydrologists for near-surface flow. Earthquake epicenters would not be expected to fall along rivers in this model because of the directions of the paths that subsurface groundwater flow takes from recharge areas (highlands) to discharge areas (rivers).

A change in water level of less than 1 meter (< 0.1 bar) is enough to trigger seismicity in some areas. The deepest reservoirs add stress loads of only about 20 bars, not enough to break unfractured rock. Deep reservoir-induced earthquakes are therefore evidence for preexisting water-filled fractures already in place; the most likely cause of the seismicity is the result of a small increase in fluid pressure along with hydrolytic weakening that triggers the release of a large prestress along a preexisting fracture systems in a crust already tectonically stressed close to failure.

All four principal earthquake areas in the southeastern U. S. are within gravity-driven groundwater basins that can provide an abundant supply of meteoric water to the crust and that intersect fractured crust. The host

groundwater basins have the largest surface recharge areas and contain rivers with the highest average stream gradients as measured from their headwaters to the Fall Line, thus making gravity-driven groundwater flow the most efficient in these higher-gradient basins. Seismicity in the eastern United States is characterized by *diffuse* alignments and/or clusters of earthquakes, words that are commonly used to describe fluid diffusion. The earthquakes themselves indicate displacements that are compatible with steep to vertical faults that are currently being reactivated by diffusion of groundwater from surface recharge of groundwater basins. If changes in pore pressure can be confirmed by ultradeep monitoring, the Hydroseismicity model has the potential for forecasting Earthquake occurrence.

SUMMARY

In conclusion, I strongly support the proposed Continental Scientific Drilling Program. Drilling in the oceans for scientific purposes played a critical role in developing plate tectonic theory. Drilling on the continents is no less important. We lack a complete understanding of how plates are deformed when they split apart and how thrust sheets are formed when plates collide. We have reached a point in our interpretation of reflection seismology data when some of our ideas about the thicknesses and compositions of thrust sheets should be tested by ultradeep drilling. One consequence of the plate interactions is faulting and fracturing of the plates to great depths. Some of these fractures are still open, and we believe they are connected and transmit water. Somehow, in the interiors of plates, we believe water plays an important role in triggering earthquakes. The ADCOH Project will address many of these problems.

References

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National Academy of Sciences (1979) Continental Scientific Drilling Program, US Geodynamics Committee, Geophysics Research Board, National Research Council, 192 p.

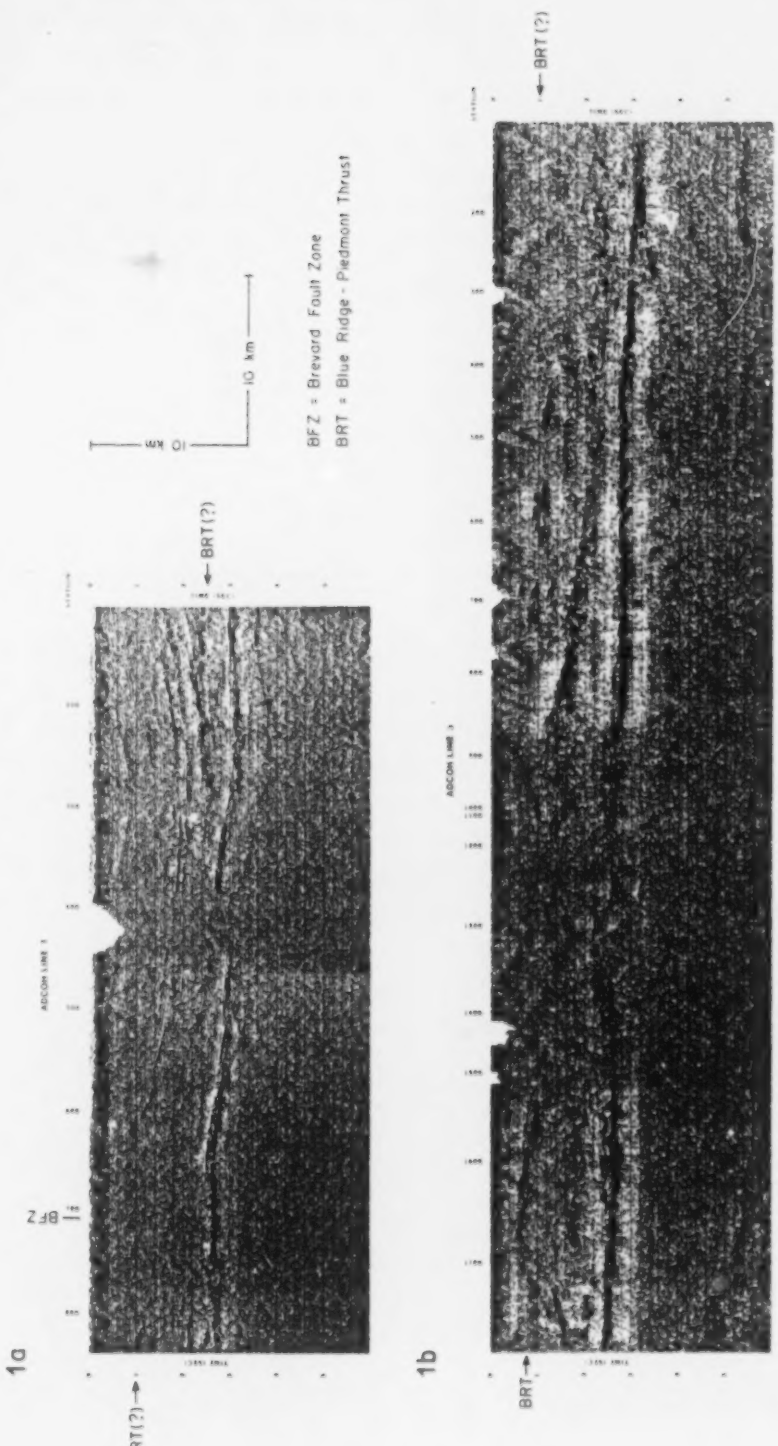
1a
BFZ
BRT(?)
BRT(?)
10 km
10 km
BFZ = Brevard Fault Zone
BRT = Blue Ridge - Piedmont Thrust
1b
BRT(?)
BRT

Figure 1

Senator WARNER. Thank you very much, Doctor. I have been able to look through other portions of your testimony here.

All right, we will now have Dr. Shock from Lawrence Livermore National Laboratory.

Dr. Shock.

STATEMENT OF DR. ROBERT N. SCHOCK, EARTH SCIENCES DEPARTMENT, LAWRENCE LIVERMORE NATIONAL LABORATORY

Dr. SCHOCK. Mr. Chairman, I want to thank you for the opportunity to appear before you today. With your permission, I will simply summarize my prepared testimony and cover only the salient remarks that I believe are most important.

I will do that in the context of my position as head of a large Earth sciences organization at a national laboratory. In that position, I am very familiar with the role that the Earth sciences plays in a wide variety of programs of national importance. Just some of these are the verification of compliance of test ban treaties by seismic means, the extraction of energy from geothermal resources and fossil energy deposits, and the safe encapsulation of nuclear waste for very, very long periods of time.

All of these programs demand a detailed knowledge of the Earth's continental crust and how it has behaved as a function of time. At the same time I am also aware of how little we know about the Earth's crust, and also the tremendous effort that we put as a scientific community and as a nation into developing indirect means of telling us what is down there in that continental crust.

So it is in this context that I believe it is important and it is timely to proceed with a national Continental Scientific Drilling Program. By now other speakers have emphasized that the continents are really a small volume of the total Earth. They are only 20 to 30 miles thick. Yet in this volume, as we are all aware, exists most of our energy in mineral resources, and it is the place where we have to dispose of the waste byproducts of our society. It is also the origin of many of the hazards to this society, such as earthquakes and volcanoes.

We have estimated the total volume of this crust which is already small in how much of it has been looked at. It is certainly no more than a tenth of 1 percent, and some of our estimates are that it is less than one one-hundredths of a percent that we have actually looked at to find out what is there.

In addition, most of that exploration that has taken place in the crust has been in the uppermost crust and in sedimentary basins primarily associated with the exploration for petroleum, which as you know has gone on for some time. I think it is not unfair to say that our knowledge about the rest of the crust outside of sedimentary basins is similar to what we knew about those sedimentary basins before the great petroleum exploration programs began early in this century.

We have made tremendous advances as a nation and as a science in geophysical techniques to explore the deep continental crust and to find out what is there. However, we need to remember that we can only infer what is there. What we have done is to send energy down, or look at energy that has passed through the deep earth

and use our interpretation of that, or interpret how that energy comes back up out of the crust to find out what is there.

It is really only an inference, and we cannot be sure that our inferences are correct. This has come home very loud and clear by looking at some of the results from the Soviet deep drilling program, some of which have already been mentioned. A particular, very prominent seismic anomaly that the Soviets drilled through was found to contain no significant differences in the rocks that were there, and so an inferred anomaly turned out to apparently have not been an anomaly.

They also found, as has been mentioned, fluids flowing at depth where all of our theories thought that fluids could not flow. So the point is that by actually getting down in the crust to the point and checking what these inferred hypotheses were telling us, we found out that in fact they were wrong.

So what this Continental Scientific Drilling Program is really all about is verifying the hypotheses of a scientific community that have accumulated over the years. Many scientists can go to the laboratory to perform an experiment in an attempt to verify hypotheses. The important point is that the Earth scientists must go to where the process is either taking place now or has taken place, and that is to the Earth, and use drilling to find out what is happening in the third dimension.

I believe that now is the time to do this, and that it can be done for a very modest amount of funds. There are examples of successful drilling that are far more reaching than just the petroleum industry. I mention just in passing, you have heard and you will hear in the speaker to follow me about some tremendous successes from a very modest program that the Department of Energy and the other agencies that are represented here today have carried out in the geothermal area. There are a host of programs, some of which you have heard about and others which you will hear about, which treat different scientific problems, things like resolving the controversies over the magnitude of stresses that accumulate along fault systems. There is a great deal of controversy about that, and if we are going to understand the devastating effects of earthquakes and understand those fault movements, we need to comprehend what those forces are.

You have just heard about the proposed deep hole in the southern Appalachians. That will test the hypothesis of whether there are perhaps sedimentary rocks underlying crystalline rocks. If there are, there are tremendous implications for that in terms of understanding the continental crust, as well as perhaps resources that exist or may exist in those sedimentary rocks.

Over the past 2 years I think it has been very significant that the entire geoscience community has become involved and has in fact proposed major drilling projects at more than 30 sites throughout this country. Those projects are aimed at attacking long unresolved problems.

The constituency for this type of program, which I think is important, is broad. It involves scientists from various disciplines, not just the Earth scientists but certainly all of the disciplines within the Earth sciences—scientists from universities, private industries,

government institutions, and supported by several Federal agencies.

I do not think since the lunar exploration program have the world's Earth scientists been so enthusiastic and so unified about the prospects for success in a program and what we will get out of it.

I do not want to leave the subject of what will come from this program without mentioning what Dr. Otte touched on in great detail. That is, that the temperatures, the pressures, and the corrosive fluids and the hard-rock types that we expect to encounter will demand major advances in drilling and instrumentation technology. So that has to go hand in hand with this program. It is obvious that the spinoffs from that technology development will benefit the Nation as a whole, not just this program.

I would like to conclude by giving you an example of what I believe is the need for a Continental Scientific Drilling Program and for the support of Congress in this endeavor. It is an illustration, really. Every science is replete with illustrations of why one has to verify hypotheses. The one I would like to use is that after World War II, most well-respected geoscientists had rejected a very old idea, and that idea was the idea of mobile drifting continents.

Arguments were raised by a few people from time to time in favor of continental drift, and in general they were rejected categorically based on what had been well-established hypotheses. The evidence that ultimately disproved those hypotheses and in fact led to revolutionary thinking about our Earth and its evolution came from drilling and sampling and the recovery of samples from the sea floor.

So hypotheses that had been created in the minds of very smart people wilted when they were faced with the physical evidence that came from the drill hole. I believe we are at a similar juncture today in our understanding of the continental crust which is beneath us, and the time is at hand to prove or disprove the many hypotheses that are out there which deal with the nature of that continental crust. The evidence of natural phenomena is in the rocks, and we must sample these rocks to know what they hold, and this program will do that.

Thank you very much.

[The prepared statement of Dr. Schock follows:]

Statement of Dr. Robert N. Schock
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before the

Subcommittee on Natural Resources Development and Production

of the

Senate Committee on Energy and Natural Resources

July 24, 1986

Mr. Chairman and Members of the Subcommittee:

I want to thank you for the opportunity to appear before you today to discuss the proposed Continental Scientific Drilling and Exploration Act. In my position as the head of a large earth sciences organization at a national laboratory, I am familiar with the role of the earth sciences in a wide range of programs having national importance. These programs involve verification of compliance of test ban treaties by seismic means, the extraction of energy from geothermal reservoirs and fossil fuel deposits, and the safe encapsulation of nuclear waste for very long time periods. They all demand a detailed knowledge of the earth's continental crust and its behavior over time. I am also aware of how little we know about the crust, and the tremendous effort we as scientists and as a nation expend to develop indirect means of telling us more about it. In this context I believe that it is time to proceed with a national Continental Scientific Drilling Program.

The continents make up about one-third of the surface area of the earth, and are only about 20 to 30 miles thick. Yet this volume contains most of our energy and mineral resources, and it is the place where we must dispose of most of the waste by-products of our civilization. It is also the origin of many of the natural hazards to society, such as earthquakes and volcanoes. However, we estimate that the volume of the crust we have drilled is much less than 0.1% of the total, and almost all of that drilling has been in the uppermost crust in sedimentary basins while exploring for petroleum. What we presently know about the rest of the crust can be compared with what we generally knew about sedimentary basins before the famous Spindletop field was drilled in Texas at the turn of the century. Before the great petroleum drilling programs, we only knew that oil occurred in seeps at the surface.

Despite tremendous advances in geophysical techniques for exploring the deep continental crust by indirect means, we can only infer what is there, often only on a large scale. Even then we cannot be sure that our inferences are correct. For example, the Soviets have reported that they observed no changes in rocks as they drilled 6 miles deep where seismic methods had indicated a significant discontinuity. They also found fluids at great depths where no one thought fluids would flow. It is very important for the scientific community to verify what our geophysical tools are telling us about the deep crust, and the only way to do that is to drill and core and bring samples back to the surface for study and examination. In this way, the Continental Scientific Drilling Program can verify hypotheses that have been developed over the years by accumulated evidence. Many scientists go to the laboratory to perform an experiment in an attempt to verify a hypothesis. The earth scientist must go to where the experiment has already taken place, namely the earth, and see the picture in the third dimension. Now is the time to do this, and it can be done for less than $100 million per year.

Examples of successful continental drilling programs are more far-reaching than just the petroleum industry. Over the past several years the Department of Energy has followed its mandate for studying thermal regimes with a small-scale program to drill shallow to intermediate-depth holes in areas of thermal activity so as to understand the processes associated with the formation and intrusion of magma, as well as the subsequent release of heat

and mineral-bearing fluids. As a result, the program has identified the source of a 600-year-old volcanic chain (Figure 1); shown that paths for magma are created when gas from the magma cracks the rock and is followed to the surface by the molten liquid; observed how minerals deposit in an active hydrothermal system; defined the heat inventory for a circulating hydrothermal system; and shown that localized thermal zones are likely to be responsible for the heat in a major area of continental rifting. However, we must drill deeper to determine the extent of geothermal resources and to understand the heat transfer and mineral formation processes that take place at depths where magma and water initially come in contact.

There are a host of scientific problems beyond thermal resources and mineral formation--all of which are important to us--that can only be solved by deep drilling. Geoscientists will soon begin drilling a deep hole along the San Andreas fault (Figure 2) to resolve controversies over the magnitude of the stresses that accumulate along a major fault system. Much of our understanding of the devastating effects of fault movements rests on our comprehending these forces. A deep hole has been proposed in the southern Appalachians (Figure 3) to test the hypothesis that crystalline rocks have been thrust horizontally over very long distances and now overlie very deep sediments. If verified, this hypothesis will impact our understanding of the origin of mountains and the formation of the continental crust itself.

Over the past 2 years, the entire geoscience community has become involved and has proposed major drilling projects at more than 30 sites to attack long-unresolved problems. These projects range from the Illinois basin, the Texas Gulf coast, the Cascades, and the Alaskan peninsula, to the Black Hills of South Dakota, the plains of Kansas, and the volcanoes of Hawaii. The scientific objectives of these projects include an understanding of the processes involved in the formation of crust 2.5 billion years ago, a look at the bottom of a deep sedimentary basin to look for clues to its origin, and the definition of newly formed land along continental margins. The constituency for this type of program is broad and involves scientists from various disciplines and from universities, private industry, and government institutions, supported by several federal agencies. Not since the lunar exploration program have the world's earth scientists been so enthusiastic and unified.

The temperatures, the pressures, the corrosive fluids, and the hard-rock types that such a program will encounter require major advances in drilling and instrumentation technology. New drills, drill string material, sampling methods, and logging tools must be developed. Their development will be of great benefit to the nation, in much the same way that the advances in petroleum drilling and sampling technology in the early part of this century have benefited many other industries.

The need for a Continental Scientific Drilling Program and for the support of Congress in this endeavor is best illustrated by reminding ourselves how science operates and how it progresses. After World War II most well-respected

geoscientists rejected the very old idea of mobile, drifting continents. Any arguments in favor of continental drift were rejected categorically based on well-established hypotheses. The evidence that ultimately disproved those hypotheses and led to revolutionary thinking about our earth and its evolution came from the drilling and recovery of samples from the sea floor. Hypotheses that had been created in the minds of great men in their offices wilted when faced with the earth's own evidence. We are at a similar juncture today in our understanding of the continental crust beneath us, and the time is at hand to prove or disprove the hypotheses. The evidence of natural phenomena is in the rocks, and we must sample those rocks to know what they hold. The Continental Scientific Drilling Program will allow us to explore much of the crust that is at present virtually unknown, increasing our understanding of our energy and mineral resources as well as volcanic and earthquake hazards; advancing drilling and sampling technology; improving our knowledge of seismic transmission in the crust, thus increasing our ability to verify test ban treaty compliance; improving our confidence about the long-term safety of underground waste disposal; and greatly expanding our scientific data base.

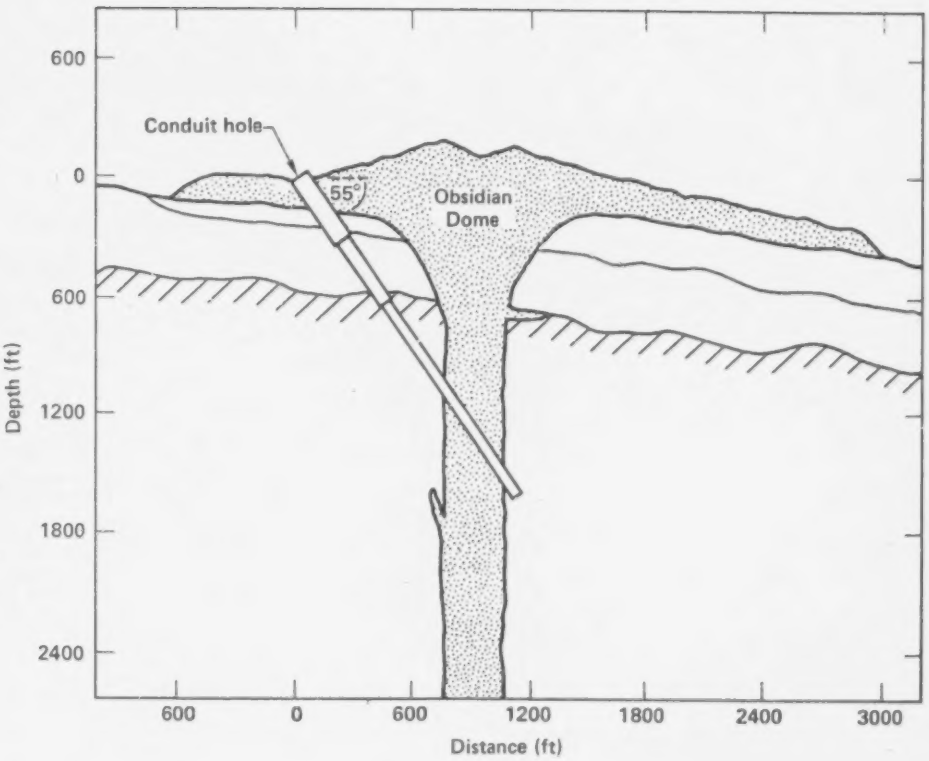

Figure 1. Cross section of Obsidian Dome, California, on the eastern slope of the Sierra Nevada, showing the intersection of a shallow drillhole and the feeder conduit to the Dome. From Eichelberger, J. D., and P. C. Lysne, "Research Drilling at Inyo Domes, Long Valley Caldera, California," EOS Trans. AGU 65(39) (Sept. 25, 1984).

Figure 2. Location of a proposed drill site along the San Andreas fault near Cajon Pass, Southern California.

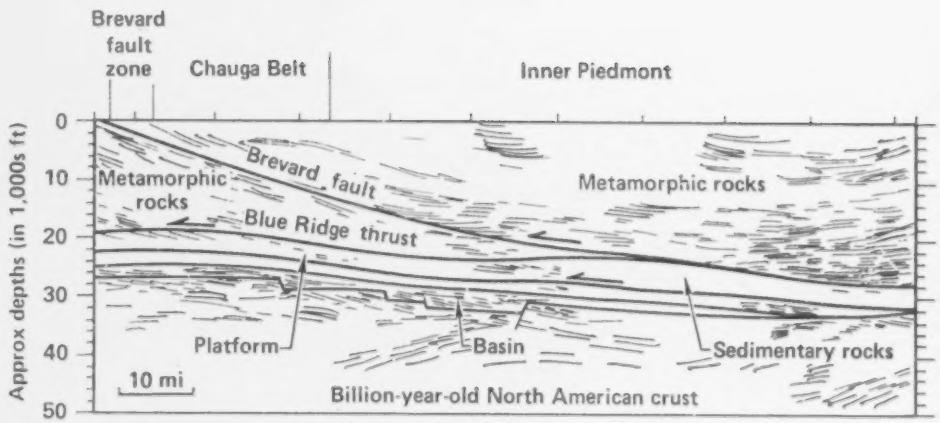

Figure 3. Profile across the southeastern Appalachians showing possible thrust faults that are thought to have resulted from the collision of two continents. From Hatcher, R. D., S. H. Edelman, and R. T. Williams, The Appalachian Ultradeep Core Hole (ADCOH) Project, A Primer, Department of Geology, U. of South Carolina, Columbia, South Carolina 29208.

Senator WARNER. Thank you very much, Dr. Schock.
We will now hear from Dr. Elders.

STATEMENT OF DR. WILFRED A. ELDERS, PROFESSOR OF GEOLOGY, UNIVERSITY OF CALIFORNIA

Dr. ELDERS. Mr. Chairman, my name is Wilfred Elders. I am a professor at the University of California. Following your suggestions, I will briefly summarize the remarks I have submitted for the written record.

As the chief scientist of the Salton Sea Scientific Drilling Project, which was the first major research bore hole in the United States of the Continental Scientific Drilling Program, I know from personal experience that this proposed legislation is necessary, and I would like to give you some background for that assertion.

Although the results of past geological processes can be studied at outcrops, drilling is the only practical method of studying the active processes going on beneath the surface of the Earth. We cannot, for example, directly measure stresses responsible for earthquakes without drilling into zones where earthquakes are generated.

Similarly, we cannot directly observe the processes responsible for geothermal phenomena without directly drilling into the hot zones.

Until recently, although there was a widely perceived need for continental scientific drilling, there was also a wide sense of frustration by many scientists, including myself, because there seemed to be no practical way of implementing a program. But in the fall of 1982 I proposed to drill an exploratory research well in the Salton Sea geothermal field of California, which is one of the largest and hardest geothermal fields in the world.

However, there seemed to be no way to implement the program. Therefore, I became a lobbyist for the project. As a result, Congress appropriated $5.9 million for what became known as the Salton Sea Scientific Drilling Project. This was in the Department of Energy's Division of Conservation and Renewable Energy.

Then an interagency committee was formed with coordinated participation on this project by the National Science Foundation, the U.S. Geological Survey, and the Department of Energy. We sought the widest possible participation by the scientific community, and the roughly $2.5 million cost of these research activities came jointly from the research budgets of these agencies.

Our aims in drilling this well were to probe the roots of the very hard geothermal system. This picture on my left is a picture of the drill rig at the south end of the Salton Sea.

[Picture shown.]

Dr. ELDERS. The well was successfully drilled between October 1985 and April 1986. Highlights of this project were: we drilled the hottest well at 665 degrees Fahrenheit, and the deepest well at 10,564 feet, so far drilled for scientific purposes. We demonstrated the commercial potential of deep resources, and had very high flow rates.

[Picture shown.]

Dr. ELDERS. The next picture shows one of these flow tests in progress at the well. The rock cores we obtained in drilling this well demonstrated an amazing transition from lake sediments to hardly altered hard rocks with abundant ore minerals.

[Picture shown.]

Dr. ELDERS. The next picture shows some of the ore minerals in one of the cores. This is an example showing ores of copper and iron in this rock. Several hundred scientists and engineers participated.

[Picture shown.]

Dr. ELDERS. Here, for example, is one of the engineers at one of the control valves in the steam line. Now at the beginning we had interinstitutional problems. But as the program developed, we had an excellent collaboration between Government, industry, and university people and overcame many challenging organizational, technical, and scientific problems.

Now I have emphasized the Salton Sea Scientific Drilling Project because it epitomizes the reasons why we need to organize a national program of continental scientific drilling on a secure footing with long-term planning and funding. While the Salton Sea project was very successful, I do not believe that it is the way that we should do things. If every scientist with a good idea for exciting research had to become a lobbyist, then the work of Congress would grind to a halt by the weight of bearded professors stuck in the gears. [Laughter.]

During the lifetime of the Salton Sea Scientific Drilling Project there has been a rising tide of enthuasism for the concept of continental scientific drilling. In 1984, as you have heard, DOSECC was formed as a consortium of universities. In 1985 DOSECC was inundated by a flood of excellent proposals for drilling. Meanwhile, as you have heard, the Department of Energy has done some shallow drilling in thermal regimes proprietary to identifying deeper targets.

By this summer it was clear that the momentum attained by the continental scientific drilling was unstoppable. Some idea of the range of the current and future activities is shown on this map, which is part of the written record. This map was simply based upon projects that were reported on or mentioned at an international conference held in Rapid City, SD, in June.

Of the current projects shown in purple, seven of them are in volcanic or thermal regimes; one project studies the state of stress and heat generation associated with earthquakes along the San Andreas Fault.

The major projects proposed for the future, which are in yellow, are very eclectic in their scope. Once more, many of them involve active volcanic, thermal, or tectonic processes. Some of these proposals will push available technology to its limits.

As you know, geology developed in the 19th century by painstaking study of the surface of the continents. Twenty years ago, as we have heard, geology was revolutionized by new systematic studies of the ocean floors. We have now reached the limit of these traditional approaches. To progress, geologists must drill to study the active processes shaping this planet.

Therefore, I urge you to support this legislation and future activities to support continental scientific drilling. Let science drive the drill.

Thank you.

[The prepared statement of Dr. Elders follows:]

STATEMENT IN SUPPORT OF "THE CONTINENTAL SCIENTIFIC DRILLING AND EXPLORATION ACT", (S. 1026)

by

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and

Chief Scientist
Salton Sea Scientific Drilling Project

Submitted to the

"SUBCOMMITTEE ON NATURAL RESOURCES, DEVELOPMENT AND PRODUCTION",

of the

"COMMITTEE ON ENERGY AND NATURAL RESOURCES", UNITED STATES SENATE

Hearings
July 24, 1986

Mr. Chairman, Members of the Committee, Ladies and Gentlemen:

I am pleased to be here today to commend Senator Larry Pressler for introducing S.1026, and to urge your support for it.

As Chief Scientist of the Salton Sea Scientific Drilling Project, the first major research borehole of the U.S. Continental Scientific Drilling Program, I know, from personal experience, that this proposed legislation is a necessary step in implementing a viable, comprehensive, and truly national program. It will provide a basis for many exciting projects which are receiving enthusiastic support from the earth science community.

I would like to begin by reviewing some background to the Continental Scientific Drilling Program. Then I will share with you some of the frustrations, and some of the rewards of being involved in proposing a major scientific drilling project, seeking funds for it, implementing it, and the excitement of succeeding in meeting its scientific objectives. Then I want to mention some of the other scientific drilling projects recently completed or under way, and some of the future prospects.

During the last two decades the space program led to a revolution in our concepts of the nature and origin of the moon and the planets. In the decade of the 1960's there was a similar revolution in our understanding of the Earth. During that time "plate tectonics" was developed as a new and revolutionary theory. According to this idea, the outer rocky shell of the Earth is divided into eight or nine large plates which move relative to each other, interacting in complex ways where they touch. Much of the verification for this theory resulted from the Deep Sea Drilling Project (DSDP), a highly successful national drilling effort initiated in 1968.

The DSDP showed that the ocean crust has been formed in the last 200 million years by plate tectonic processes; thus it made a major contribution to the revolution in the earth sciences, as targets of major scientific importance were identified, and drilled, in the oceans. A DSDP organization with the full backing of the ocean science community came into being, with much of the leadership in planning and implementing the program coming from academic institutions. However, industry and government agencies participated actively in the program and used the impressive body of data which became available.

During this time, clamor for a complementary drilling program on land was less strident, even though the continental crust evolved over a much longer time and is much more complex than the ocean crust. Although the number of geologists and geophysicists studying the continents was much larger than that studying the oceans, many of these scientists were involved in applied or in economic geology, or tended to focus on problems of local rather than continental scale. Furthermore, the large amount of drilling on land was carried out by industry for oil or other resources and, to a lesser extent, by federal and state agencies in response to the demands of their specialized missions. For example, three or four years ago, at the height of the petroleum exploration boom, tens of thousands of boreholes were drilled for various purposes each year in the U.S.A. and its adjacent territorial waters. Some of this drilling resulted in successful oil wells. The deepest of them reached depths of about six miles, but most of them were quite shallow. Although these numbers seem impressive, you should remember that 6 miles is only 0.15% of the distance to the center of the Earth.

Even more disappointing to me is that rather little science emerged, at least to the public domain, from this industry and government drilling activity. This is not due to a conspiracy by petroleum companies to frustrate

advances in geology, but the result of business considerations. Firstly, because these wells were sited for commercial reasons, they were not necessarily favorably situated for scientific studies. They were mostly drilled in sedimentary basins. Secondly, because drilling is an expensive activity, organizations drilling wells have, in general, neither the motivation nor the time to permit experimentation in their wells by research scientists. Finally, because of the expense involved, information and data gained from drilling is regarded by industry as a valuable commodity which can be sold or exchanged. Thus, in this country, most information from industry drilling is kept proprietary. Similarly, although a government agency such as the Department of Energy carries out drilling as part of its mission in weapons research and energy technology, these activities are not usually available for participation by the scientific community.

It was in this context that drilling the continents for scientific purposes was debated for many years.[1] However little progress was made until recently. Although interest and motivation was high, there seemed to be a lack of focus and organizational structure to launch the necessary national program. In a sense, setting up an organization for ocean drilling came more easily. Studying the rocks beneath the oceans required, at the very least, the level of the organization necessary to support oceanographic vessels, whereas studying the rocks cropping out on dry land required no more than a pair of stout boots and a sure hand with a hammer, and so required much less organization.

Because the oldest rocks of the continents approach 3.9 billion years in age, the continental crust has been subjected to numerous

[1]For a discussion and bibliography of this debate see U.S. Geodynamics Committee, 1979, "Continental Scientific Drilling Program", National Research Council/National Academy of Sciences.

upheavals. The record of these upheavals may be read from the rocks as we can find samples of formerly deep-seated rocks at the surface today. Much of our understanding of the the interior of the earth beneath the continents comes from studies of such rocks. However these rocks are samples of the results of processes long since over. There is, therefore, a limit to what we can learn from surface samples to study the processes which shape the outer rocky crust of the earth. We cannot, for example, directly measure the stresses responsible for earthquakes without drilling into the zones where earthquakes are generated. Similarly we cannot directly observe the processes responsible for geothermal phenomena without drilling directly into the hot zones, and measuring the temperatures and sampling fluids in place. There are many other geologic processes, such as volcanic eruptions and mineral ore formation, which are actively going on today, and which will only be properly understood by developing the technology to permit direct measurements and sampling, in research boreholes.

Thus, although the results of past geological processes can be studied at outcrops, drilling is the only practical method of studying the active processes going on in the subsurface of the Earth. There was a widely perceived need for Continental Scientific Drilling, but many scientists until recently had a deep sense of frustration, because although a lot of drilling was going on, there was no ready mechanism to implement a scientific drilling program.

My personal frustration with this situation caused me to make a direct appeal to the U.S. Congress on behalf of a specific project. For several years my institute at the University of California had been involved in scientific investigation of geothermal fields. In the Fall of 1982 I learned that a resource company planned to drill an exploratory well in the Salton Sea geothermal field, one of the largest, and hottest geothermal fields in the

world. The company concerned agreed to my proposal that, if we secured funds to deepen the well they would make it available for study by the scientific community. However there seemed to be no practical way to do this through the institutions charged with supporting basic research. Discussions with the National Science Foundation, United States Geological Survey, and Department of Energy made it clear that these agencies had neither the mandate nor the funds to carry out this proposal, even though it was receiving widespread support from fellow scientists. I became a lobbyist pro tem for what became known as the Salton Sea Scientific Drilling Project (SSSDP). As a result, Congress added an appropriation of $5.9 million for the SSSDP to the FY84 budget of the Department of Energy's Division of Conservation and Renewable Energy. After a lengthy procurement action, it was too late to follow the original plan and the DOE awarded a contract to a consortium consisting of a different resource company and a major engineering company, as operator, to drill a new well.

Later an interagency committee was formed in a pioneering action to coordinate participation specifically on this project by the National Science Foundation and the United States Geological Survey with the Department of Energy. This committee has worked in a way which augurs well for future collaboration in Continental Scientific Drilling. The widest possible participation by the scientific community was encouraged and more than 40 different groups of investigators were funded. The roughly $2.5 million costs of these activities came jointly from the research budgets of these agencies, rather than from a specific appropriation.

Our aims in the SSSDP were to probe the roots of a very hot geothermal system, a unique, hostile, high temperature/pressure environment never before properly investigated. By drilling and testing a deep and very hot research

well, we have also advanced the basic science and technology underlying development of geothermal resources. The well which was successfully drilled between October 1985 and April 1986, is the hottest and deepest research well drilled in the U.S.A. to date.

Highlights of the SSSDP include:

- a depth of 10,564 ft and temperatures of 665° F were reached;
- the commercial potential of deep geothermal resources, with extremely high flow rates of up to 790,000 lbs/hour, was proved;
- 734 ft of rock cores were obtained, demonstrating transitions from lake sediments to highly metamorphosed rocks with abundant ore minerals;
- igneous rocks intruding the sediments were penetrated, which may be related to the heat source;
- samples of steam and of brine containing up to 25% of metal-rich salts were obtained from two different levels;
- an extremely comprehensive and technologically sophisticated series of downhole experiments and measurements was successfully concluded, and state of the art systems for logging and sampling hot, saline, environments were tested;
- several hundred different scientists and engineers from more than 30 different laboratories in the U.S.A. and abroad participated;
- after initial inter-institutional problems, an excellent collaboration of government, industry, and university agencies was forged in the fire of overcoming the challenging organizational, technical and scientific problems involved.

I am choosing to emphasize the SSSDP, not just out of a personal sense of achievements won after hard efforts, but because it epitomizes the reasons why we need to organize a national program of continental scientific drilling on a secure footing, with long term planning and funding. There was no precedent for the SSSDP. It was necessary to put together funding and an organization specifically to carry out this project.

While the SSSDP was very successful, I do not believe that the way in which I was forced to operate is how things should be done. I am sure the members of this Committee would prefer not to hold hearings on every earth science project proposed--even by me. If every scientist with a good idea for exciting research had to become a lobbyist, then the work of Congress would grind to a halt by the weight of bearded professors stuck in the gears.

The SSSDP met its initial scientific objectives. It will be a landmark study of geothermal phenomena. It was conceived in frustration, born in hope, but matured in success. During its lifetime there has been a rising tide of enthusiasm for the concept of Continental Scientific Drilling, more than sufficient to float a national program.

No doubt of this assertion would remain in the minds of observers at three successive international conferences on Continental Scientific Drilling. The first, in Tarrytown, New York, in 1984 led to the formation of DOSECC (Deep Observation and Sampling of the Earth's Continental Crust) as a consortium of universities supporting scientific drilling. At the second conference, in Houston, Texas, in 1985, DOSECC was inundated by a flood of excellent drilling proposals. Meanwhile, the Basic Energy Sciences program of the Department of Energy began shallow research drilling in thermal regimes, preparatory to identifying deeper targets. This program, among other things, drilled into two different volcanic systems, the Long Valley Caldera in California, and the

Valles Caldera in New Mexico. In addition shallow temperature gradients were measured in the Salton Sea geothermal field to improve definition of its nature and extent.

By the time of the third conference, in Rapid City, South Dakota, in June 1986, it was clear that the momentum attained by Continental Scientific Drilling was unstoppable. Some idea of the range of current and future activities can be gained from the attached figure (Figure 1). Its purpose is to demonstrate a maturing level of interest rather than to be a definitive statement of prospects for research drilling in the U.S.A. It is simply based upon current projects reported on, or mentioned, at the Rapid City Conference, together with those for which substantive proposals were made at that time. The order of their listing in the figure corresponds approximately to the order in which they appeared in the program of that conference.

Of the current projects seven are in volcanic and thermal regimes (1a, 1b, 7a, 7b, 13, 14a, and 14b), two of which are primarily for technology development for geothermal energy rather than basic science (13, 14a). One project studies the state of stress and heat generation associated with earthquakes along the San Andreas Fault (2). One set of studies involves crystalline basement rocks beneath sedimentary cover to unravel the geologic history of the Mid-west (3a, 3b). Finally one project is investigating a metallic ore body in Colorado to understand ore formation (24).

The major projects proposed for the future are eclectic and comprehensive in their scope. Some of these projects have not yet fixed on a specific site and so their positions on the map are tentative. Once more, many of them involve active volcanic, thermal or tectonic processes (4, 6, 9, 15, 16, 20a, 20b, 21, 23 and 26) whereas others are involved in probing deeper into complex terrains to solve various problems of geologic structure and history. Some of

these proposals are ambitious projects which would push available technology to its limits in terms of temperature (6) and depth problems (8, 25).

The science of geology developed in the nineteenth century by painstaking study of the surface of the continents. In the first half of this century this was augmented by the development of geophysical methods to infer some of the properties of rocks at depth. Twenty years ago, geology was revolutionized by new systematic studies of the ocean floors. Stimulated by these developments, we have reached the limit of traditional approaches. To progress, geologists must drill to study the active processes shaping our planet and probe deeper into its crust.

I therefore urge you to vote for this legislation and to support Continental Scientific Drilling in the future. Let science drive the drill!

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Legend and Notes for Figure 1

(A) Projects recently completed, underway, or imminent.

1a. *Salton Sea Scientific Drilling Project*[1], *and 1b Shallow Temperature Gradient Studies*[2], *Salton Sea, California.*
2. *San Andreas Fault Zone, Cajon Pass, California.*[3]
3a-3b. *Crystalline Basement of the Mid-west, Iowa and Adjacent States.*[3]
7a. *Inyo Domes*[2], *7b Long Valley Caldera, California.*[2]
13. *Newberry Volcano, Oregon.*[1]
14a. *Hot Dry Rock Project*[1] *and 14b Valles Caldera Project, New Mexico.*[2]
24. *Creede Mining District, Colorado.*[3]

[1]*Geothermal Technology Division, DOE*
[2]*Basic Energy Sciences Division, DOE*
[3]*NSF/DOSECC*

(B) Projects recently proposed.

4. Alaskan Peninsula island arc-trench system.
5. Harney Peak Granite, Black Hills, South Dakota.
6. Magma Energy Project, Long Valley, California.
8. Appalachian Ultradeep Core Hole, South Carolina.*
9. Katmai Volcano, Alaska.
10. Mid-continent Rift System, Minnesota to Kansas.
11. Grenville Province in the Mid-Continent basement, Ohio and adjacent states.
12. Texas Gulf Coast.
15. Active Subduction, Middleton Island, Gulf of Alaska.
16. Program for Scientific Drilling in the Cascades, Oregon.
17a-b. Continental Interior Crustal Studies Consortium, Southern Trans-Hudson Transect, South Dakota.
18. Southern Margin of the Colorado Plateau, Arizona.
19. Basement of the Suwannee Basin, North Florida.
20a. Deep Sampling of Accreted Terranes, Central Alaska.
20b. " " " " " , Western Washington.
21. Sevier Desert Basin, Utah.
22. Minnesota Archaen Gneisses, Minnesota.
23. Coast Range Thrust System, Coalinga, California.
25. Illinois Superdeep Drillhole Project, Illinois.*
26. Deep Drilling in the Hawaiian Volcanoes.

*Very deep boreholes.

Figure 1. Current and Proposed Scientific Drilling Project in the U.S.A., June 1986: A partial list.

Senator WARNER. Thank you very much, Dr. Elders. That was quite informative.

We will now hear from Mr. Eidel of the Illinois Geological Survey.

STATEMENT OF J. JAMES EIDEL, PRINCIPAL GEOLOGIST AND HEAD, MINERAL RESOURCES GROUP, ILLINOIS STATE GEOLOGICAL SURVEY

Mr. EIDEL. Mr. Chairman, Dr. Morris Leighton and myself have submitted a lengthy testimony. He is chief of the Illinois Geological Survey.

Rather than summarizing that, I would like to pick and choose a few comments that I do not think have been heard before, and provide an example of what this program means to the States.

We would like to call the committee's attention to the fact that, in addition to Federal support for a Continental Scientific Drilling Program, the National Governors' Association has adopted a resolution in favor of Continental Scientific Drilling. The policy was offered by Governor Thompson of Illinois and passed unanimously at the August 1985 National Governors' Association meeting. The policy reads:

> The Governors recognize the importance of continued scientific investigation into the geologic processes of formation and transformation deep within the earth's crust. In recent years, the United States has lagged behind the drilling projects which are far more extensive than any in the United States. The Governors support legislation which establishes a national program of deep drilling, and further support continued funding of the National Science Foundation's budget of this important program.

I would also like to add that no one has called attention to the fact that many geology-related professional organizations have recognized the need for and endorse the Continental Scientific Drilling Program. These include the American Association of Petroleum Geologists; the Society of Economic Geologists; and the Society of Petroleum Geologists.

The complexities of continental evolution can only be unraveled by addressing the third dimension, and that can only be done with the drill. The third dimension alludes us, especially in the United States midcontinent region where the strata are flat-lying, providing sheet-like cover of still deeper strata.

To give you an idea of the nature and socioeconomic benefits of a program of continental scientific drilling, we have selected a specific example: the proposed Illinois Basin ultradeep hole in the midcontinent, one of a number of candidate locations.

The grassroots support of the proposed Illinois hole is considerable and is an example of what can be expected from the States; 125 U.S. geoscientists recently convened in a workshop to address ultradeep drilling. That workshop was supported by the Illinois Department of Energy and Natural Resources, the Oregon University's Trust Fund, the Illinois Environmental Protection Agency; the University of Illinois; and DOSECC.

The hole is of scientifically vital interest because it will explore why some 100,000 cubic miles of flat-lying rock in the Illinois basin of Illinois, Indiana, and Kentucky was added to the continent pre-

cisely at the intersection of underlying rifts or fundamental continental breaks.

Some 80 to 90 similar basins have been identified elsewhere in the world. A number of these basins produce significant quantities of hydrocarbons, including basins in the United States, Scandanavia, France, Poland, Great Britain, and Austraila. Deep data from the Illinois basin will help in assessing the potential of other national and international similar but little explored basins.

Examination of the potential socioeconomic benefits of a midcontinent hole such as the Illinois basin hole will serve to illustrate the potential benefits of a Continental Scientific Drilling Program to a group of States.

Due to the flat-lying nature of midcontinent rocks, earthquake energies are transmitted over greater distances than anywhere else in the United States. The disastrous Missouri New Madrid earthquake in 1811 and 1812 rattled dishes in Boston. Reactivation of midcontinent rifts continues today at the rate of 200 earthquakes per year in southern Illinois and adjacent Missouri.

We simply do not have measurements of the state of stress and strain at the depths where those earthquakes occur. The proposed Illinois basin hole will address earthquake preparedness and monitoring by emplacing a seismometer that will be superquiet, and in addition it will detect nuclear explosions.

The likelihood of deep, old fluids in basin rocks provides an opportunity to address ultradeep disposal of brines, hazardous wastes, and radioactive wastes. If such fluids are identified as expected, there will be a new concept of ultradeep disposal.

Finally, with respect to socioeconomic benefits, the hole would encourage exploration by addressing the origin and distribution of mineral resources, including both oil and gas, and strategic and nonstrategic minerals. It has been predicted that the next continentally important ore deposit to be discovered in the United States will be discovered at depth in the midcontinent.

In conclusion, we recommend that given the scientific and societal benefits that are expected, the U.S. Federal Government should support the Pressler bill to explore the frontiers we live above at the same time we continue to explore space and the oceans. The potential benefit at home on our continent exploring inner space is infinitely greater.

Thank you.

[The joint statement of Mr. Eidel and Dr. Leighton follows:]

Testimony to Senate Subcommittee on Natural Resources, Development, and Production

July 24, 1986

on

Senate Bill 1026

The Continental Scientific Drilling and Exploration Act

Statement of J. James Eidel
Principal Geologist and Head
Mineral Resources Group

Morris W. Leighton, Chief

Illinois State Geological Survey

CSDP/ISD Testimony to Congress on Continental Scientific Drilling and Exploration Act

Introduction

I wish to testify today on behalf of the bill proposing the Continental Scientific Drilling and Exploration Act, Senate Bill #1026.

By way of introduction (Fig. 1), I have spent four years on the NAS/NRC Continental Scientific Drilling Committee where I chaired the Panel on Mineral Resources. After twenty-two years of domestic and international mineral exploration (by drilling), I joined the Illinois State Geological Survey as its Principal Scientist and Head of the Mineral Resources Group in early 1985 where I shepherded the Illinois Basin Ultradeep Drillhole (IBUD) from a concept to one of the two most both mature and scientifically and economically sound proposals for a U.S. ultradeep drillhole. The IBUD has the largest scientific constituency of any U.S. ultradeep drillhole proposal. This constituency is part of an even larger group that recognizes that deep drilling is required to explore one of our remaining frontiers -- the deep subsurface, the earth's continental crust. Outer space and the oceans have received considerable attention in recent years, yet inner space, the deep subsurface beneath our feet, is little explored.

The co-author of this statement, Morris W. Leighton, is Chief of the Illinois State Geological Survey. He spent 32 years with Exxon Corporation in domestic and international oil exploration and research. He was actively involved in the application of offshore scientific information gained from the offshore Drilling Program (formerly known as JOIDES) and is convinced, as I am, of the need for a parallel on-shore drilling program for scientific purposes and of the desirability of exploring "inner space."

We are convinced that fundamental questions regarding the evolution of our continental crust can be answered only by deep drilling. The complexities

of continental evolution can only be unravelled by addressing the continent's third dimension.

PART I: THE CONTINENTAL SCIENTIFIC DRILLING PROGRAM

What Is CSDP?

The Continental Scientific Drilling Program (Fig. 2) being developed by the National Science Foundation, the United States Geological Survey, and the Department of Energy through its operating agency, DOSECC, is the only type of program that can provide the scientific answers to the many questions posed by the scientific community, industry, and the lay public on the nature of our deep subsurface environment. The program consists of both holes of opportunity and holes dedicated solely to deep scientific drilling. Holes of opportunity are those industry holes that may by deepened for specific scientific purposes. Dedicated holes are those initiated by scientific planning to meet specific scientific needs. Dedicated holes, rather than holes of opportunity are often required inasmuch as industry holes are not necessarily drilled to maximize scientific data. Rather they are drilled to maximize immediate economic payout. It is the aim of the Continental Scientific Drilling Program to use both types of holes to seek the answers scientists need concerning the nature of U.S. deep and ultradeep geology.

A Continental Scientific Drilling Program should add immensely to our understanding of the Continent just as the Offshore Drilling Program, formerly known as JOIDES, did for the origin of our oceans and the oceanic crust beneath it. Cores of sediments and underlying crystalline rocks were the foundation for the program just as cores will be the foundation for the CSDP. From core, determinations were made of ages of sediment, processes of basin development and structuring of the earth's crust, the record of evolution of life, and the history of worldwide climatic changes. A more

complete understanding of the Earth, the past and present was obtained. The results of the Deep Sea Drilling effort included confirmation of ocean floor spreading, determination that the oceans's rock and sediments are young (less than 200 M years old or one twentieth of the earth's age), and that sections of the sea floor have travelled thousands of miles. The Deep Sea Drilling program also provided new insights on the formation of the earth's mineral resources and the wealth of offshore areas. The many startling discoveries assured the success of that program.

Just as assuredly, a properly planned and conducted Continental Scientific Drilling Program will provide equally startingly new insights and discoveries about our continental crust, generally thought to be lighter, more buoyant, and thicker than the oceanic crust.

Why Do We Need A CSDP?

Impact of Offshore Drilling - The scientific necessity of a CSDP is clear. The successful Ocean Drilling Program (ODP) has enabled us to reconstruct geologic history and understand the evolution of the earth and its natural resources back to about 200 million years ago (see Fig. 3). Yet the oceanic rock and sediments encountered back to this point in geologic time represent only 4% of the earth's history. On the other hand, rocks composing the continents represent 82% of the earth's history. The rocks at depth, representing the older history of our earth, are virtually unsampled for scientific purposes.

Knowledge gained from the intensive offshore drilling program has, as yet, not been fully incorporated into our analysis and understanding of the development of our continents. International effort at sea over the last three decades allowed the development of plate tectonic theory that described the movements of oceanic crust and of continents as plates moving on a less rigid mantle. Even though we have a much more detailed knowledge of the

continental surface than we have of the sea floor, we have barely begun to apply plate tectonic theory gleaned from the oceans to the continents. The scientific understanding of the much more accessible continental crust representing most not a small fraction of earth history, is poorly understood.

As compared to the continents, the deep ocean floor requires intensive and expensive effort to recover ocean floor resources. Oil companies are still mastering the drilling of the most accessible offshore margins. There still exists potential for greater economic benefit by carrying out a scientific drilling program on the continents in areas more accessible to industry, utilizing existing technology and know-how. Being in a position to rapidly utilize scientific findings in the nation's interests, i.e. in our own backyard -- on the accessible continents is of utmost economic importance to America.

Views of National Authorities - The necessity of a Continental Scientific Drilling Program has also been made abundantly clear through the efforts of distinguished authorities and groups who have assembled, discussed, and reported on national priorities. We have listed here (see Figure 4) the most important meetings, workshops, and events, and reports that now define continental scientific drilling needs.

The workshop at Ghost Ranch in 1974 and the succeeding report by the U. S. Geodynamics Committee strongly supported the development of a national program of drilling. The 1979 NAS report on Continental Scientific Drilling stated that:

> "The dynamics, structure, evolution, and genesis of the continents offer a major scientific challenge. The geoscience community responded to earlier challenges: the geographical challenge through exploration; the planetary challenge through spacecraft missions; and

> the challenge of the ocean depths by sampling from the ocean surface, by exploration with submersibles, and by drilling. Now the challenge is on land."

This report made the principal recommendation that "a Continental Scientific Drilling Program be initiated to achieve expanded knowledge and understanding of the uppermost part of the crust of the earth in the United States ....."

In 1983, the National Research Council and the National Academy of Sciences issued a report on "Opportunities for Research in the Geological Sciences." That report noted that:

> "Effective strategy for research in the geosciences over the coming decade can be built around investigating the physical and chemical character of the crust by deep-scientific drilling."

More detailed and accurate definition of the structure and composition of the continental lithosphere was considered to be "of overriding importance and priority" over all other of the seven fundamental geologic topics that were considered as having great promise for advancing geology in the next decade (1984-1994).

Also it was noted that:

> "Least understood are regions of uplift and subsidence with intraplate areas, such as the central mid-continental portion of the United States. Relations between plate tectonics and intraplate tectonic activity require continued research to determine how much intraplate activity is related to plate motions and how much is related to independent causes" (p. 32).

The report went on to say that:

> "A program of drilling holes dedicated to scientific studies is highly recommended over the next few years, as the structure of the continental crust becomes better understood. Just as critical areas of the oceanic crust have been tested by the drill with remarkable results, similar exciting discoveries can be anticipated from a program of continental scientific drilling. Such a program would be expensive, but the returns would be great" (p. 80).

Also the document continues:

> "Deep holes drilled entirely for scientific reasons or 'dedicated deep drilling' have always been a wistful gleam in the eyes of geologists but have always seemed too expensive in comparison with other needs. Now, however, based on the information we are getting about the deep continental structures from geophysical probes, we are rapidly approaching the time when direct sampling by drilling will be the only way to calibrate geophysical data. We believe that dedicated drilling on the continents requires immediate planning and drilling should be undertaken in 3 to 5 years." That is now.

Until the Continental Scientific Drilling Committee (CSDC) was organized under the NAS/NRC in 1980, there was no systematic national effort to monitor U. S. industry and government agency drilling and drillholes of potential scientific merit. The Continental Scientific Drilling Committee (CSDC) provided both a mechanism for recognizing holes of opportunity and a catalyst for encouraging scientific cooperation and necessary funding to add science to holes of opportunity. At the same time, CSDC panels on basement structure and deep continental basins, active fault zones, thermal regimes and mineral resources defined the scientific and societal objectives in their particular fields and sought dedicated drilling targets that would fulfill these objectives.

Thus, considerable sophistication has been developed in defining needs for deep drilling, both scientific and socio-economic. Documents emanating from the CSDC and DOSECC have sought to recognize and list the fundamental questions regarding the evolution of the continental crust that are necessary to advance our knowledge of the earth -- questions that can only be answered by deep drilling. Scientific needs have been cited in the fields noted in Figure 5.

These documents also recognize societal needs, both social and economic, as important as or more important than the scientific needs. These are summarized in Figure 6.

Scientific models have been developed to predict the occurrence and behavior of materials deep in the subsurface anticipating the scientific and societal needs. Unfortunately, there are no other means of testing earth models formed from surficial geologic mapping and seismic, gravity and magnetic measurements, of measuring the physical attributes of rocks; or of sampling the rocks and the fluids they contain other than by drilling. The key phrase is measurement. The only manner in which subsurface direct measurement can be carried out is with the drill. Without subsurface core samples for post-drilling geologic, geochemical, and geophysical experimentation and down-the-hole geophysical measurement there can be no CSDP and no real advancement of our understanding of the continents. Consequently, the CSDC determined that a continuing National Program of Continental Scientific Drilling is required, extending over a period of decades and dealing with a variety of critical problems in continental crustal structure, tectonics and evolution as improvements in technology make them feasible...(Priorities for a National Program of Continental Drilling for Scientific Purposes, National Academy Press, 1984).

Many geology related organizations recognized the need for and endorsed the Continental Scientific Drilling program as it developed including the American Association of Petroleum Engineers and the Society of Economic Geologists.

In addition to federal support for a CDP, the National Governors Association has adopted a resolution in favor of the Continental Scientific Drilling Program as follows: "The Governors recognize the importance of continued scientific investigation into the geological processes of formation and transformation deep within the earth's crust. In recent years, the United States has lagged behind -Insert A- drilling projects, which are far more extensive

Insert A - the Soviet Union and other countries which have implemented substantial deep

than any in the United States. The Governors support legislation which establishes a national program of deep drilling, and further support continued funding in the National Science Foundation's budget of this important program." This proposed policy was offered by Governor Thompson of Illinois and passed unanimously at the August 1985 National Governors' Association meeting.

Needs for Competitive Edge and Enhanced Investment Climate - Needs for a Continental Scientific Drilling Program are also apparent when we consider our competitive position vis-a-vis other foreign countries (Fig. 7). To retain our competitive edge and foster our image as a country in which to invest, we need to ensure that our nation is on the cutting edge of science and technology. We also need to ensure appropriate participation and communication on the subject within the international geologic community to effect scientific synergism that will make scientific and technical progress both more rapid and cost effective. A perspective view of the international scene and our resulting needs follows:

- In the United States, we have gained considerable information from the 30 to 80,000 oil wells drilled each year. We have learned a great deal about the subsurface mainly at shallow depths. Unfortunately, oil wells have been and still are being drilled primarily in the shallow positions of our sedimentary basins. They are not distributed in a homogeneous fashion and avoid many areas requiring scientific study. They average about 4000 feet in depth. They rarely penetrate the basement rocks below the continental sedimentary veneer and when they do often no core is taken of basement -- core that is vital to science.

- In the United States, several wells have been drilled to depths greater than 26,000 feet using conventional rotary techniques. Five of these are in Oklahoma at depths of 26,402', 26,903', 29,241', 29,312', and the deepest well in the United States at 31,441'. There are eight wells drilled deeper than 26,000' in Texas. The deepest well in Louisiana is 25,703' and in Wyoming 25,764'. All of these holes were drilled for economic, not scientific purposes and therefore do not have samples, cores, and logs adequate for a number of scientific studies.

- Only the USSR has an active continental scientific drilling program; however the Federal Republic of Germany has allocated $138 M to drilling one of the sites and are actively developing alternative plans for drilling a pilot hole.

- The USSR has more than taken the lead in continental drilling. A book on the now famous Kola Superdeep Drillhole is being translated into English and will be published this year. The Kola hole is over 39,000 feet (13,000 meters) deep at a temperature of over 3200 F (2000C); it is the deepest continuously cored hole in the world. The USSR core hole provides a solid cylindrical sample suitable for scientific study while normal rotary-drilled U.S. oil wells provide an incoherent sample composed of small chips that are unsuitable for most scientific purposes. The U.S. must make the technical transition to deep coring in order to be able to acquire adequate scientific samples.

  The Russians have accepted visitors at the Kola site and at Saatly, near the Caspian Sea where the second hole of a twenty hole program is in progress. Field trips to both sites were conducted in conjunction with the CCCD meeting at the 27th International Geological Congress in Moscow, August 1984. (Frank Stehli and Bob Andrews of DOSECG, Kate Hadley of Exxon, and Wilf Elders, Chief Scientist of the Salton Sea Scientific Drill Project visited the Kola SG-3 hole).

- Within the international scientific community, an International Lithosphere Program was instituted in 1980. The Inter-Union Commission on Lithosphere established a Coordinating Committee: Continental Drilling (CCCD) to develop mechanisms for international and inter-disciplinary communication and cooperation in the scientific use of opportunities for continental scientific drilling and the results of measurements made in connection with such drilling; to investigate the possibilities offered by the new instrumental technology for scientifit measurements in deep boreholes; and to encourage international collaboration in deep drilling in the continents. Members of the CCCD are the United States, USSR, Federal Republic of Germany, Belgium, France, Japan, Iceland, Austria, Czechoslovakia and Great Britain.

  The CCCD and Lamont Doherty Oceanographic Institute sponsored an International Symposium on Observation of the Continental Crust through drilling at Tarrytown, New York in 1985 that has since been published. The symposium included presentations by the Federal Republic of Germany, Czechoslovakia, France, Belgium, Japan, Sweden, and Austria. A second International Symposium on Observation of the Continental Crust was held in Germany in October 1985.

It is obvious that Russia has an established lead in deep continental scientific drilling. Efforts are advancing rapidly in Germany. Action is required in the United States if we are to be at the cutting edge of deep drilling technology, remain in the scientific forefront of deep geological investigation, and enhance our image as a place for future economic investment.

The Space Analogy

The history of the space program serves to illustrate the immense potential for economic spin-offs of frontier basic research. The value of communication, navigation, and weather satellites, fuel cells, computer technology and technique, prediction of mineral resources, medical technology, new concepts in air travel, the use of "space suits" in foundries, extension of ball-bearing life, and the use of ion thrusters in cutting, joining, cleaning and coating surfaces, altering surface properties, preparing semiconducters, improving ion microscopes and in ionic vacuum pumping; and many other technological advances are the result of space effort. The results of "earth" effort can, like the space effort during its inception only be guessed. Like the space effort, the earth effort will also likely be of national security value. The emplacement of an ultradeep seismometer will be a superquiet detector of nuclear blasts.

Needs for a CSDP Summarized

The needs for a Continental Scientific Drilling Program are thus summarized as fourfold (see Figure 8):

- To utilize and expand on the scientific results already available from the successful Ocean Drilling Program
- To meet the Scientific and Socio-Economic Needs Specified by National Authorities
- To remain at the cutting edge of science in a leading, competitive position, enhancing our image as a country in which to invest.
- To take advantage of expected spin-offs for mankind.

How can A Continental Scientific Drilling Program Be Accomplished?

Financial Support: The Continental Scientific Drilling Program must have federal support if it is to get off the ground. The Ocean Drilling Program

(ODP), as it is known today is an outgrowth of the Deep Sea Drilling Program (DSDP) started in 1968 and concluded in 1983. Committment to a similar 15 year program of Continental Scientific Drilling is expected to pay dividends similar to the DSDP. The DSDP program logged 375,000 miles in 96 voyages, drilled 1,092 holes at 624 sites and yielded sixty miles of core. The latter is vital to any scientific drilling program.

Onshore, deeper drilling will be undertaken. Vital coring will slow the process. It is expected that two deep holes will be underway each year with each drill hole requiring from three to five years to drill. Clearly, the CSDP is an expensive undertaking. Just as clearly, the CSDP is the only route to developing the scientific and societal benefits described herein.

Program Management/Guidance

The DSDP was managed by JOIDES with Scripps Institution as the lead institution. The current ODP is managed by Texas A & M. Significant industry involvement on advisory committees and in providing personnel support helped to make the program the success it was.

As in the offshore program, industry is expected to play a vital role, providing counsel and advice, data and technology, and volunteer effort. It should not be expected to finance this program of scientific exploration of inner space any more than industry in the U.S. could have been expected to finance the $170 billion dollar space program, lunar exploration; recognizing nevertheless that the endeavor led by NASA was of ultimate utility to industry and the public given the scientific and technological advances that resulted from the program. A similar government-industry relationship may be envisioned for the Continental Scientific Drilling Program with the added advantage being the utility of industry's collective drilling experience to date. The possibilities will continue to be investigated of deepening an industry hole for scientific purposes, if that hole is fortuitously situated

on a site offering scientific opportunity to the CSDP. Nevertheless, dedicated scientific holes must be the principal focus of the CSDP.

It is also clear that such programs will require close cooperation with the various States involved. These programs involve large scale, complex science and technology issues. The 1983 Opportunities for Research in the Geological Sciences report on continental scientific drilling addressed the issue of organization to tackle the needed large scale, complex program and it stated that "Although much of the needed research can be done by individual researchers with basic grant support, consortia should be formed as needed to work on large problems involving major equipment and facilities for multidisciplinary and interdisciplinary investigations" (p. 9). It went on to say that "The earth sciences, through the unification provided by the plate tectonics theory, have reached the stage where a consortium approach can yield large dividends and where costly experiments and facilities are required to attack obvious problems too large for individual investigators. NSF should support these teams vigorously" (p. 79).

Recommendation

Given the need for a Continental Scientific Drilling Program and given the scientific and societal benefits described herein, it is recommended that the U.S. federal government support the Pressler Bill (S.B. #1026) to explore the frontiers we live above at the same time we continue to explore space and the oceans. The potential benefit at home on our continent is infinitely greater.

PART II: THE ILLINOIS BASIN ULTRADEEP DRILLHOLE: AN EXAMPLE OF CONTINENTAL SCIENTIFIC DRILLING

Introduction

As we have noted, the complexities of continental evolution can only be unravelled by addressing the third dimension and that can be done only with

the drill. The third dimension eludes us especially in the Midcontinent region where the strata are flat-lying providing sheet-like cover of still deeper strata. To give you an idea of the nature and benefits of a program of Continental Scientific Drilling, we have selected a proposed drillhole location in the mid-continent -- one of a number of candidate locations. Planning for the Illinois drillhole has progressed to a point where we can describe it and its science plan in considerable detail. This hole provides an example not only of the scientific value of an ultradeep drillhole but an example of the potential socio-economic benefits to any given state or group of states. I will discuss first the need for this drillhole and the benefits to be derived from drilling it.

Need for Illinois Basin Untradeep Drillhole

Recognizing a geologically significant area, the Illinois State Geological Survey has proposed a technically feasible 30,000 core hole (Fig. 9). The hole is of scientifically vital interest because it will explore why 90,000-100,000 cubic miles of sediment was added to the continent precisely at the intersection of underlying rifts or fundamental continental breaks. The area is in southern Illinois, a part of the Illinois Basin, at the intersection of the Reelfoot/New Madrid rift system within the Mississippi Embayment area and the Rough Creek/Shawneetown graben system of Kentucky and Illinois. Evidence suggests that the Illinois Basin was initiated by doming and subsequent faulting. Rifts developed within the continent of North America. These were later followed by gentle crustal subsidence -- what we refer to as sagging.. Understanding the Illinois Basin rift-sag relationship will help to explain how the intracontinental basins that contain so much of our fuel and mineral resources were formed and how these were redistributed into economic oilfields and ore deposits.

Some 80-90 basins have been identified with similar rift-sag relationships elsewhere in the world. A number of these dual cycle rift/sag basins produce significant quantities of hydrocarbons including:

Sirte Basin, Libya
Ghadames Basin, Algeria/Libya
North Sea, Great Britain/Scandinavia
Irish Sea, Great Britain
Paris Basin, France
Polish Basin, Poland
Wessex Basin, Great Britain
Bowen, Cooper, & Surat Basins, Australia

Comparative data from these basins including the Illinois Basin will help in assessing the potential of other similar but little explored basins (Fig. 10).

While the basins sited above have a common economic interest, the scientific factors that controlled their evolution, their formation and preservation are little understood. For example, the control of plate tectonics in continental evolution becomes progressively obscure in geologically older terrains. Drilling these terrains is the only way to obtain the "hard" scientific data required. The focus on a mid-continent site was noted in Continental Tectonics (1980). This report stated that:

> "Least understood are regions of uplift and subsidence with intraplate areas, such as the central mid-continental portion of the United States. Relations between plate tectonics and intraplate tectonic activity require continued research to determine how much intraplate activity is related to plate motions and how much is related to independent causes."

Measurements of geologic age, rates of sedimentation for given geologic sequences, thermal history, and paleomagnetism are needed at depth to study and resolve plate motions and crustal activity and to establish the relations between plate tectonics and intraplate activity.

One major scientific need stands out above all others -- the need to understand the evolution of our continental crust and resulting sedimentary basins. What were the geologic controls for the development of an intra-

cratonic basin, that constructively added 100,000 cubic miles of sediment to our continent? The Committee on Opportunities for Research in the Geological Sciences addressed the Evolution of Sedimentary Basins as follows:

> "Most sedimentary basins in the United States have been explored to some degree and many have been studied extensively in the search for petroleum. Outstanding questions that remain are discussed at length in the NRC report, Continental Margins (1979), which points out the need for systematic basin studies. Although a good start has been made in relating basin development to plate tectonics, available knowledge is not sufficient to determine fundamental factors that control the location and size of basins, the relationship between the formation and the evolution of basins and the sediments found in them, and the factors that affect the conversion of sediments into rock and of buried organic matter into fluid hydrocarbons."

> "A more complete understanding of the tectonic, sedimentological, and diagenetic (post-burial) history of sedimentary basins is important not only for finding useful resources within them, but also for understanding earth processes related to fluid movements with the basins. For example, the origin of basins and their compaction history have a direct bearing on quantities and qualities of groundwater in the basins. The disposal of our nation's increasing quantities of waste products requires a much more intensive study of the properties of basin sediments (NRC report, Geological Aspects of Industrial Waste Disposal, 1982)."

> "The origin and development of sedimentary basins on the continents are linked to the nature and action of the underlying continental basement. The subsidence process is complex, involving tectonic thinning of continental crust, thermal cooling of lithosphere, tectonic flexure of lithosphere, and the direct effects of local sediment loading. Understanding of the nature of the basement provides insight into basin development and permits meaningful predictions about basin history and economic significance."

Concentrating on the mid-continent region, DOSECC-SAC concluded in their 1985 report to the NSF on Cratonic Processes that:

> "Wide sampling of cratonic basement is essential to understanding the evolution of continental crust through time. Many important ore deposits occur within Precambrian basement rocks of cratons and other ore deposits, as well as fossil fuels, occur within the overlying Phanerozoic cover. A better understanding of crustal evolution would enhance our knowledge of the genesis of such resources."

> "A full understanding of cratonic evolution requires integrated study of both basement and Phanerozoic cover, which in the past have generally been studied separately. Many problems, such as heat flow, fluid migration, earthquake generation and active rift faulting associated with the central Mississippi seismic region, can only be understood through such integrated investigations. In the continental interior of

the United States, large portions of the crystalline basement are covered, so answers to major questions regarding crustal evolution are accessible only by drilling. Studies of samples obtained from holes of opportunity drilled for petroleum and mineral exploration have provided much data in the past and represent an important industry contribution to the program. However, in many critical areas that lack obvious economic potential, there is no prospect for such opportunities and dedicated, scientific drilling is the only recourse."

"Major questions relating to Phanerozoic cover that can only be addressed by drilling and coring include: 1) stratigraphy and sedimentology of hitherto undrilled strata, especially in the deepest portions of cratonic basins, 2) the study of fluids and their relations to diagenesis, petroleum generation and Mississippi Valley type ore deposits, and 3) the expression and history of deep structures that originate in the basement but extend upward into Phanerozoic cover."

The 1984 DOSECC proposal to NSF noted that:

"the process by which subsidence begins, the thinning of the lithosphere, and the complex interactions involving sedimentary deposition, flexure of the crust, compaction, and further subsidence, followed by heating of the roots of basins, thermal modification and expulsion of the fluid fractions, all still constitute one of the most exciting scientific puzzles of this century," (1984, p. 6).

With increased understanding of the evolution of the Illinois Basin, societal needs can also begin to be addressed, for example society's need for identifying and assessing the volumes of fuel and non-fuel mineral resources, for defining hydrodynamic regimes needed for the safe containment of hazardous toxic chemicals and of both low level and high level radioactive wastes, and the need for national security in our ability to detect nuclear explosions.

Benefits

The Illinois Basin Ultradeep Drillhole (Fig. 11) will provide:

1) the first continuous core at or near the depocenter of an intracratonic basin. It will thus provide the first continuous record of the events that caused the basin, and a penetration of the structures and rocks beneath the basin that are related to the basin-forming processes. The U.S. Geodynamics Committee pointed out that broad areas of subsided continental crust such as the Illinois Basin are characterized by subsidence that apparently occurred intermittently and at varying rates over hundreds of millions of years and that such long continuing vertical movements may reflect changes in the thermal regime beneath a continent (Geodynamics in the 1980's, National Academy Press, 1980, p. 18),

2) a determination of the thermal history of the Illinois Basin,

3) a reinterpretation of the existing body of mid-continent seismic and potential field geophysical data by recalibration using direct measurement of physical properties at depth and from previously unattainable samples,

4) an unparallelled set of paleomagnetic determinations, allowing continuous evaluation of the rotation of the North American Plate,

5) characterization of contemporary stress at the rift complex inter section,

6) the first examination of the lower 4000-7000 feet of Illinois Basin sediments, their geologic history, geotechnical properties, types and amounts of organic matter, and data on enigmatic Illinois Basin brines,

7) an evaluation of the possibility of Proterozoic sediments and or volcanics in the rift environment,

8) information to complete the hydrologic-paleohydrologic models of the Illinois Basin, and

9) the first examination of the roots of the Illinois-Kentucky Fluorspar District and associated rift-related mineralization.

Four major areas of research were addressed by four CSDC panels at Los Alamos in 1978 (Fig. 12):

1. Basement Structures and Deep Continental Basin,
2. Earthquakes,
3. Mineral Resources, and
4. Thermal Regimes.

The geology of southern Illinois and the proposed Illinois Basin Ultradeep Drillhole (IBUD) will provide a major contribution to the scientific understanding of the first three of these research areas. Useful information will be provided on the fourth. The direct and continuous observation of both the basin and basement rocks beneath it will for the first time allow the construction of a consistent, comprehensive model of an intracratonic basin. The IBUD will also provide a test of the combined models of mid-continent crustal rifting and loading, thermal expansion and contraction and the resultant episodic subsidence, sedimentation and isostatic readjustment.

Hinze et al., (1980, p. 73-83) have reviewed models for mid-continent tectonism including the present day seismic reactivation of the Reelfoot Rift. These data were gathered and published as part of the USGS/NRC New Madrid Seismotectonic Study. The models are qualitative and will remain so without calibration of geophysical observations with geological data. Stratigraphic data and information on rock properties at depth is vital. The IBUD will provide such data allowing for more precise, less speculative models. As Art Green, Exxon Production Research Company has noted:

> "The type of crust that underlies a sedimentary basin determines the physical framework, stability, structural style, and conditions of sedimentation and environment throughout the evolution of the basin. Thus as sediments are deposited, they record the tectonic history of the basin. These stratigraphic data can be used to develop conceptual genetic models that put the evolution of oceanic, continental, and transitional types of crust into perspective."

The accumulated data from an Illinois Basin Ultradeep Drillhole will contribute significantly to an analyses of basin evolution. As noted in the NAS/NRC Publication, "Opportunities for Research in Geological Science":

> "The main thrust in basin analysis is the development of integrated quantitative models of basin evolution. If successful, these specific models can supplant the general qualitative views of the past and bring new benefits to all applications of basin studies. All the following facets of basin analysis are amenable to systematic vigorous quantitative treatment: (a) the operation of the depositional systems responsible for the sedimentation of the strata within the basins, (b) the diagenetic processes of compaction and cementation that convert loose sediment to coherent rock, (c) thermal maturation of organic matter to hydrocarbon compounds, (d) lateral and vertical migration of contained fluids through porous sediment or rock, and (e) the rate of subsidence of the substratum as it receives a gradually thickening pile of sediment."

Thus, the processes that cause an intracratonic basin will be addressed in the IBUD project. The knowledge gained will be of global benefit.

Examination of the potential societal benefits of the IBUD will serve to illustrate the potential benefits of the CSDP.

1. Due to the flat-lying nature of mid-continent rocks, the transmissivity of earthquake energies is more widespread than anywhere else in the U.S. The New Madrid earthquakes in 1811-1812 rattled dishes in Boston. While the emplacement of a deep, superquiet seismometer in the IBUD will not facilitate earthquake prediction or help man to control earthquakes, it will become an important part of a mid-continent seismograph network that will monitor mid-continent earthquake activity, detect nuclear blasts, and help describe the mid-continent structure related to the rift complex. It is likely that increased knowledge of earthquakes will increase our ability to predict or coexist with these phenomena.

2. The Illinois Basin is characterized by oil field brines, the disposal of which causes considerable environmental and economic problems. Because of our lack of knowledge of the deepest sediments in the basin and deep basin hydrology, the origin of these brines is unknown. The IBUD will delineate the origin of these brines and explore the potential for both deep brine disposal and liquid hazardous and low-level radioactive wastes. The possibility of deep, permanent fluid disposal in the relatively non-reactive thick clastic section is of immense potential societal benefit. The contribution of the IBUD to the understanding of crustal dynamics and Illinois Basin hydrodynamics is essential. The deep regions of the continent characterized by very old waters, indicating stability and lack of movement, are virtually unstudied. Study of these deep, old waters may provide the key to safe ultradeep disposal of hazardous and low-level radioactive waste because if these fluids have been at depth and stable for hundreds of millions of years, they will most likely continue to be stable. It is essential that as our population increases and we continue to consume unrenewable resources and use increasing volumes of irregularly replenished groundwater that we intensify our ability to understand, discover and wisely use these resources and safeguard mankind by safely disposing of that which we do not consume.

3. By exploring the previously unexplored lower 4000-7000 feet of sediments in the Illinois Basin, the deep potential for oil and/or gas will be evaluated. The nature of the organic matter will be studied to establish whether the rocks are barren, oil prone, or gas prone. The existence of seals and of the nature of reservoir rocks, if any, will be established.

4. Proterozoic rift systems contain major ore deposits in other countries. By drilling into the rift complex below the Illinois Basin, the relation of the fluorspar-rich Illinois-Kentucky fluorspar district and the Hicks Dome F-Be-Th-rare earth mineralization to the underlying rift environment may be successfully evaluated. This will greatly increase our knowledge of mid-continent Proterozoic mineral potential. Mid-continent mines in Proterozoic rocks will, by necessity, be deep mines with little or no ultimate impact on the earth's surface.

We conclude that an ultradeep drillhole at or near the depocenter of the Illinois Basin that penetrates the rift complex below that depocenter promises

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to explore not only the evolution of an intracratonic basin but the tectonic, thermal, and isostatic causes of intracratonic basins, i.e., the fundamental craton-forming process. We suggest that no ultradeep drillhole proposed to date addresses such fundamental, multi-geodisciplinary goals with as broad societal implications.

Status of IBUD

In April 1985, the Scientific Advisory Committee (SAC) of DOSECC, Inc., accepted an IBUD preproposal (Fig. 13) as one of the 14 (out of 32) projects considered for initiation within the next 3 to 5 years (1988-1990). DOSECC recommended "class-specific" workshops followed by submission of a formal proposal "in order that worthy projects can be assigned priority in the drilling program." It also recommended that proposals that already exist, such as that for an ultradeep hole in the Illinois Basin, should be brought to a mature stage so that comparisons can be made and priorities set.

To date only the IBUD has had a workshop (April 1-4, 1986) for the purpose of constructing a detailed scientific plan. At that workshop, 125 IBUD scientists, representing some 25 universities, 6 state geological surveys, 8 oil companies, 5 service companies, the USGS, Argonne National Laboratory and DOSECC prepared a draft science plan for the Illinois Basin Ultradeep Drillhole. More than 80 geoscientists agreed to form a consortium to address the plan, which was presented in draft form to DOSECC on June 12, 1986. A geophysical proposal for site definition of the IBUD is being drafted that will call for field effort to select a precise location by late 1988 or early 1989. Drilling would require 4 to 6 years. A second workshop to identify and address drill technology as applied to the IBUD is anticipated.

For the first workshop, fifty-two thousand dollars ($52,000) were raised by the ISGS from the Illinois Department of Energy and Natural Resources,

Argonne Universities Trust Fund, University of Illinois Campus Research Board, the Illinois Environmental Protection Agency, and DOSECC to cover travel and workshop expenses for attending geoscientists. This workshop captured the imagination of the public who quickly recognized the idea of frontier exploration in their "own backyard."

I am pleased to report that the IBUD will fulfill all 10 of the criteria established for all dedicated deep drillholes in the U.S. by the CSDC Panel of Mineral Resources that I chaired and which were subsequently published in the CSDC Committee -- NAS/NRC report. The criteria are as follows:

Criterion 1: Scientific Impact--The research objectives must address fundamental scientific problems with potentially broad impact.

Criterion 2: National Needs--The objectives should be sufficiently broad to address research relevant to national needs (e.g., mineral resources inventory, enhanced exploration techniques, energy development, and low-level radioactive and chemical waste isolation).

Criterion 3: Broad Representative Examples--The targets should represent broad classes of geoscientific interest so that the scientific results may be applied in other regions.

Criterion 4: Background Data Available--Previous studies of the area should be in an advanced stage, allowing selection of specific research drill sites within a reasonable time frame.

Criterion 5: Scientific Efficiency--Targets should be as specific as possible to maximize the value of data obtained and to ensure achievement of the scientific objectives with minimum expenditure of time and funds.

Criterion 6: Target Uniqueness--The target should be unique in the sense that data sought are rarely available from continuous, uninterrupted rock sequences elsewhere.

Criterion 7: Well-Defined Models--Geological models should be well defined, using near-surface data to derive substantiated geometric relationships.

Criterion 8: Data Integration--Results of geophysical field studies should be integrated with surface and near-surface geological and geochemical data.

Criterion 9: Site Accessiblity--The location should be accessible to scientists and suitable for surface geological, geochemical, and geophysical studies.

Criterion 10: Environmental Impact--The site should be on property

providing no insurmountable environmental difficulties, and studies on the site should be compatible with the interests of land and mineral-rights owners.

IBUD is, however, but one of a series of deep holes needed as a part of a Continental Scientific Drilling Program.

Summary

A Continental Scientific Drilling Program (CSDP) is required (Fig. 14) to extrapolate recent plate tectonic theory explaining 4% of earth's history as developed on the ocean floor to the 82% of earth history recorded in continental rocks. Such a program is important in understanding crustal evolution and its effect on our environment and resources. The nature of flat-lying structures, the deeply covered Mid-Continent basins and basement, and poorly exposed rock sequences can only be directly explored with the drill. Continuous cores and logs are required for geologic, geochemical and geophysical characterization of the crust and crust-forming processes that enable confident extrapolation to deeper crustal and sub-crustal environments. Essential new knowledge of crustal-forming and deforming processes such as earthquake-causing stresses, near surface magma-hydrothermal fluid systems, basin-forming processes including sedimentation, and resultant hydrodynamics and resource generation can only be gained by extending our frontiers downward . . . . . with the drill.

The Illinois Basin Ultradeep Drillhole (IBUD) illustrates how a single hole can address the exploration of craton- or crustal-forming processes of potentially immense scientific and societal benefit. By probing the depocenter of the Illinois Basin above the rift complex to which the basin is related, the entire basin can be studied in one comprehensive and unique experiment of Mid-continent and global significance. The IBUD will explore:

1. crustal evolution that resulted in the Illinois Basin adding

90,000 to 100,000 cubic miles to the North American Plate,

2. the complete sedimentary history of a typical intracratonic sag formed above a rift complex, and

3. the fuel and non-fuel resource potential of the deepest basin and rift rocks, likely candidates for the source of Cambro-Ordovician oil and gas and Phanerozoic Proterozoic mineral resources.

The IBUD will provide:

1. a deep geophysical laboratory that will allow calibration and reinterpretation, and extrapolation of the body of geophysical information acquired at the surface,

2. assessment of the origin of Illinois Basin brines and possibly the origin of the Illinois-Kentucky fluorspar district,

3. construction of a complete Illinois Basin hydrodynamic model, and

4. the opportunity to assess the deep, thick clastic strata of the basin for brine and hazardous or low level radioactive, fluid waste disposal.

A Continental Scientific Drilling Program addresses one of our remaining frontiers. The CSDP is in the national interest and warrants federal support. The stakes are the maintenance of our technology and economy and the preservation of our environment.

ogs:RPIBUDCG2

Figure 1

STATEMENT ON BEHALF OF CONTINENTAL SCIENTIFIC DRILLING AND EXPLORATION ACT

- By J. James Eidel, Principal Scientist and Head of Mineral Resources Illinois State Geological Survey
  - Formerly Exploration Manager--North America, Hanna Mining Co.
  - Chairman, Panel of Mineral Resources, Continental Scientific Drilling Committee: NAS/NRC
  - Author of Concept of Illinois Basin Ultradeep Drillhole
  - Convinced of Need to Explore Remaining Deep Subsurface Frontiers
- By Morris W. Leighton, Chief, Illinois State Geological Survey
  - Formerly Chief Geologist, Esso InterAmerica
  - 32 Years with Exxon Affiliates Worldwide
  - Widely Used Information from Offshore Drilling Program
  - Convinced of Need for Parallel On-shore Drilling Program

We Conclude That Complexities of the Evolution of Our Continental Crust Can Only Be Answered By Deep Scientific Drilling, That Such Drilling Is Needed for A Variety of Sound Scientific, Social and Economic Reasons, and that The Investment Climate Will Be Considerably Enhanced By the Effort, Results, and Expected Spinoffs.

dms:ST-CSDact

Figure 2

DEFINITION OF CONTINENTAL SCIENTIFIC DRILLING PROGRAM

- A Program Developed by the NSF, USGS, and DOE
  - to investigate the nature of our continental crust
  - to implement sound scientific drilling to meet national objectives
- A Program Involving
  - holes of opportunity
  - dedicated scientific holes
- A Program To Expand On Offshore Drilling Results
  - Using cores from on-shore drilling
  - Drilling rocks more than 200 M years old (the oldest penetrated offshore)

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Figure 3

NECESSITY OF CONTINENTAL SCIENTIFIC DRILLING PROGRAM

- UTILIZATION AND EXPANSION OF OFFSHORE DRILLING RESULTS -

- Continental Drilling Is Needed to Extend Results of Offshore Drilling
  - Ocean floor geology represents only 4% of earth's history
  - Deep continental drilling depth can explore 82% of earth's history
- Offshore Drilling Has:
  - confirmed sea floor spreading
  - found sections of the sea floor have travelled thousands of miles
  - found that ocean rock and sediment are young
  - helped understand processes of basin development
  - provided structural details of the oceanic crust
  - given vital details on the history of climatic changes
  - contributed information on the evolution of life
  - provided data on subterranean mineral wealth
- Geologic Knowledge from the Oceans Needs To Be Extended To The Continents:
  - to expand on the idea of continents moving as plates on a less rigid mantle
  - to understand the evolution of continental crust
  - to concentrate the nation's effort on accessible areas
  - to concentrate the nation's effort on areas of greatest economic benefit

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Figure 4

NECESSITY OF CONTINENTAL SCIENTIFIC DRILLING PROGRAM

- Needs Identified Through Series of Workshops and Reports:
  - 1974 Ghost Ranch Workshop, New Mexico Sponsored by Carnegie Institute
  - 1978 Los Alamos Workshop Sponsored by U.S. Geodynamics Committee, Geophysics Research Board, The Assembly of Mathematical & Physical Sciences, and NRC
  - 1979 NAS Report: "Continental Scientific Drilling Program"
  - 1980 International Lithosphere Program Instituted and Coordinating Committee: Continental Drilling (CCCD) Established
  - 1980 1st Meeting NAS/NRC Continental Scientific Drilling Committee sponsored by NSF, DOE, and DOI/USGS
  - 1983 NRC/NAS Report: "Opportunities for Research in the "Geological Sciences"
  - 1984 NRC/NAS Report: "Priorities for a National Program of Continental Drilling for Scientific Purposes"
  - 1984 NRC/NAS Report: "Mineral Resources: Research Objectives for Continental Scientific Drilling"
  - 1984 NRC/NAS Report: "A National Drilling Program to Study the Roots of Active Hydrothermal Systems Related to Young Magmatic Intrusions"
  - 1984 Interagency Accord on CSD signed by DOE, DOI and NSF
  - 1985 International Symposium on Observation of the Continental Crust Through Drilling Sponsored by The Coordinating Committee: Continental Drilling and Lamont Observatory
  - 1984 DOSECC Formed and Supported by NSF
  - 1985 DOSECC Workshop, Houston, TX
  - 1985 CICSCO Workshop, St. Louis, MO
  - 1986 IBUD Workshop, Champaign, IL
  - 1985 Engineering Foundation Meeting, Sky Valley, GA
  - 1986 DOSECC Workshop, Rapid City, S. Dakota

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Figure 5

SCIENTIFIC NEEDS

Increased Knowledge and Understanding of:

- Basement Structures
- Deep Continental Basins
- Earthquakes
- Mineral Resources
- Thermal Regimes

Development of:

- Deep Drilling Equipment and Technology
- Deep Logging Instrumentation

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Figure 6

SOCIETAL NEEDS

- Increased Knowledge of Origin and Distribution of Deep Fuel and Non-Fuel Mineral Resources
- Deep Seismometer Emplacement for Nuclear Explosion Detection
- Study of Deep Disposal of Brines
- Study of Deep Disposal of Hazardous Toxic Wastes
- Study of Deep Disposal of Radioactive Wastes

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Figure 7

NECESSITY OF CONTINENTAL SCIENTIFIC DRILLING PROGRAM

- COMPETITIVE ADVANTAGE -

- Gained from Being on Cutting Edge of Science
- Gained from Participation in International Scientific Affairs
- Gained from Active, Not Passive, Role in Continental Scientific Drilling

- SPINOFFS -

- Created as in the Space Program
- Expected in Drilling Technology
- Expected in National Security Areas, e.g. Superquiet Deep Detector of Nuclear Blasts and Earthquakes

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Figure 8

SUMMARY OF NEED FOR A CONTINENTAL SCIENTIFIC DRILLING PROGRAM

- To Utilize and Expand on the Scientific Results Already Available from the Successful Ocean Drilling Program
- To Meet the Social and Economic Needs Specified by National Authorities
- To Remain At The Cutting Edge of Science Along With The Russians, Germans, and Other Leading Countries
- To Place the U.S. in the Best Position to Take Advantage of Expected Spin-Offs

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Figure 9

THE ILLINOIS BASIN ULTRADEEP DRILLHOLE (IBUD)

-- Fact Sheet -

Location:	Midcontinent, S. Illinois
Objective:	To Meet Scientific and Societal Needs
Basin Type:	Rift/IntraCratonic Sag
Features:	Reelfoot Rift & Rough Creek Graben
Depth:	Est. 30,000'
Cost:	$30-60M
Drilling Time:	4-6 years

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Figure 10

IBUD WILL ADDRESS

Scientific Needs

- Nature of Rift-Sag Basins
- Nature of Intraplate Activity
- Understanding Basin Evolution
- Geophysical Calibration

Societal Needs

- Resource Identification
- Resource Assessment
- Waste Management
- Nuclear Detection

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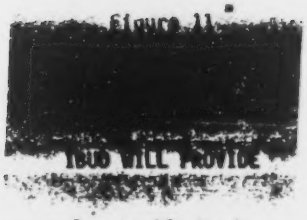

- First continuous core of sag-rift basin
- Deep geophysical observation, calibration and reinterpretation
- Temperature and pressure data
- Set of paleomagnetic determinations
- First look at oldest sedimentary rocks in basin
- Data on rift sediments and/or volcanics
- Hydrologic data and hydrodynamic models
- Paleofluid and rock chemistry

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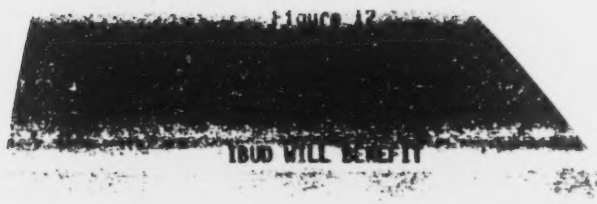

Science By Providing Understanding Of:

-- Basement Structures; Deep Continental Basin

-- Earthquakes

-- Origin of Ore Deposits

-- Thermal Regimes

-- Basin Evolution Models

Society, By Providing Information On:

-- Earthquake Monitoring & Nuclear Blast Detection

-- Brine Disposal

-- Waste Disposal

-- Oil and Gas Exploration

-- Mineral Resources

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STATUS OF IBUD

PREPROPOSAL ACCEPTED BY DOSECC

WORKSHOP HELD

-- 125 Scientists

-- Science Plan Being Drafted

SITE SELECTION BEING CONSIDERED

-- Geophysical Program Being Developed

- Site Characterization
- Site Definition

-- Generic Criteria Established

SCIENCE SITE SELECTION PROPOSALS TO BE SUBMITTED

WORKSHOP ON DRILLING PLAN REQUIRED

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SUMMARY AND RECOMMENDATION

A Continental Scientific Drilling Program (CSDP) Is Required in the National Interest

The Illinois Basin Ultradeep Drillhole (IBUD) Illustrates the Need and Expected Benefits of CSDP

The Pressler Bill (SB 1026) Should Be Supported

-- At Stake Is Our Economy and Our Environment --

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Senator WARNER. Thank you very much.

We will now hear from Dr. Mankin, Oklahoma Geological Survey.

STATEMENT OF DR. CHARLES J. MANKIN, STATE GEOLOGIST, STATE OF OKLAHOMA

Dr. MANKIN. Thank you, Mr. Chairman.

My name is Charles Mankin. I am professor of geology at the University of Oklahoma, and director of the Oklahoma Geological Survey. In that capacity I serve as the State geologist for the State of Oklahoma.

Today you have heard a great deal of information about the scientific and technical needs, or the scientific and technical support for a Continental Scientific Drilling Program. I think it is now appropriate to ask the question: Why should we have a federally supported or federally mandated program when the United States has been the site of such an extensive drilling activity by the industry?

After all, the petroleum industry alone has drilled something in excess of 3 million holes in the United States since Colonel Drake drilled the first commercial well in Titusville, PA, in 1859. In addition, countless other holes for purposes such as water supply, nonfuel mineral development, waste disposal, and construction projects could be added to this well inventory.

Although we have learned much about the shallow crust of North America from this historical drilling activity and the technology that has been developed from these efforts makes a Continental Scientific Drilling Program possible, there are at least two reasons why we cannot count on the industry alone to conduct such a program.

First, industry targets must have an obvious economic potential. Most of the identified targets for Continental Scientific Drilling do not have such an obvious opportunity. Second, based upon the present state of the domestic petroleum and nonfuel mineral industry and the administration's approach in dealing with these domestic industries, in my opinion we are witnessing the demise of these activities as we have known them.

Even if that proves to be too pessimistic a view, at the very least we will not see a significant industry drilling activity in the United States for many years. In any event, such future drilling activity by an industry, should that occur, will most likely be confined to those sedimentary basins of North America where the bulk of the historical drilling has taken place.

As you have heard today from several previous witnesses, there is a very large volume of rock in the Earth's crust under North America that are not contained within those sedimentary basins.

From the testimony of previous speakers, I believe that a scientific and technical justification for a national Continental Scientific Drilling Program has been adequately established. I do wish to emphasize that this program has broad support from the scientific and technical community. Scientists and engineers from most of the Nation's leading research universities, Federal and State Geological Surveys of which my organization is an example, and industry are united in support of this program.

For example, during the past year about 35 areas were identified for continental scientific drilling projects. Some of these have matured into carefully considered and well-designed programs, whereas others are awaiting the full implementation of such a national continental scientific drilling effort. The point is that there are a host of scientifically relevant and very exciting projects to be undertaken.

Finally, I would like to address the need for the proposed legislation. I think it is appropriate to ask the question why legislation is needed if we have an operating interagency coordinating group made up of the three Federal agencies most involved with this program.

The answer is that each agency has many priorities, of which continental scientific drilling is only one. A congressional mandate will give the program the priority that we outside of Federal Government know it deserves. Furthermore, such legislation will provide further encouragement for the three agencies involved to improve their coordination and to develop a single national continental scientific drilling effort.

The elements of the proposed legislation that I believe are needed and will ensure the successful establishment of a national continental scientific drilling effort are:

A congressionally recognized and mandated Continental Scientific Drilling Program;

An established set of important scientific objectives of this program to be accomplished;

A congressional mandate to the Departments of Energy and Interior, and to the National Science Foundation to fulfill the program's objectives through the interagency coordinating group; and

Finally, and most importantly, a required congressional review of the program.

In conclusion, Mr. Chairman, I believe this Nation needs a Continental Scientific Drilling Program. Furthermore, I believe this legislation is needed to ensure that that program is developed in a scientifically sound and cost-effective manner.

I thank you very much.

[The prepared statement of Dr. Mankin follows:]

STATEMENT OF DR. CHARLES J. MANKIN

STATE GEOLOGIST, STATE OF OKLAHOMA

before the

Subcommittee on Natural Resources Development and Production

Senate Committee on Energy and Natural Resources

United States Congress

July 24, 1986

Mr. Chairman and Members of the Subcommittee:

Drilling for the discovery and development of natural resources has been conducted in the United States for the greater part of the two centuries. Most of this drilling activity has dealt with the development of the Nation's water and hydrocarbon resources. A somewhat smaller but nevertheless important component of the overall drilling effort has involved the exploration for and delineation of deposits of coal and nonfuel mineral resources. In addition, countless, relatively shallow holes have been drilled in support of a vast array of construction projects.

Information is not available to determine with any significant degree of accuracy the total number of wells that have been drilled in the United States. However, the existing data for petroleum exploration and development provide a perspective for the overall drilling effort. Since the completion of the first commercial oil well in Titusville, Pennsylvania, in 1859, more than 3 million wells have been drilled in the United States for the development of the Nation's petroleum resources. Although most of these wells were drilled in the major petroleum-producing areas of the country, some exploration has occurred in most of the states (Fig. 1). Moreover, that drilling activity has continued at a relatively high level until recently. As Figure 2 shows, more than 750,000 wells have been drilled in the United States in the past fifteen years. By comparison, in the

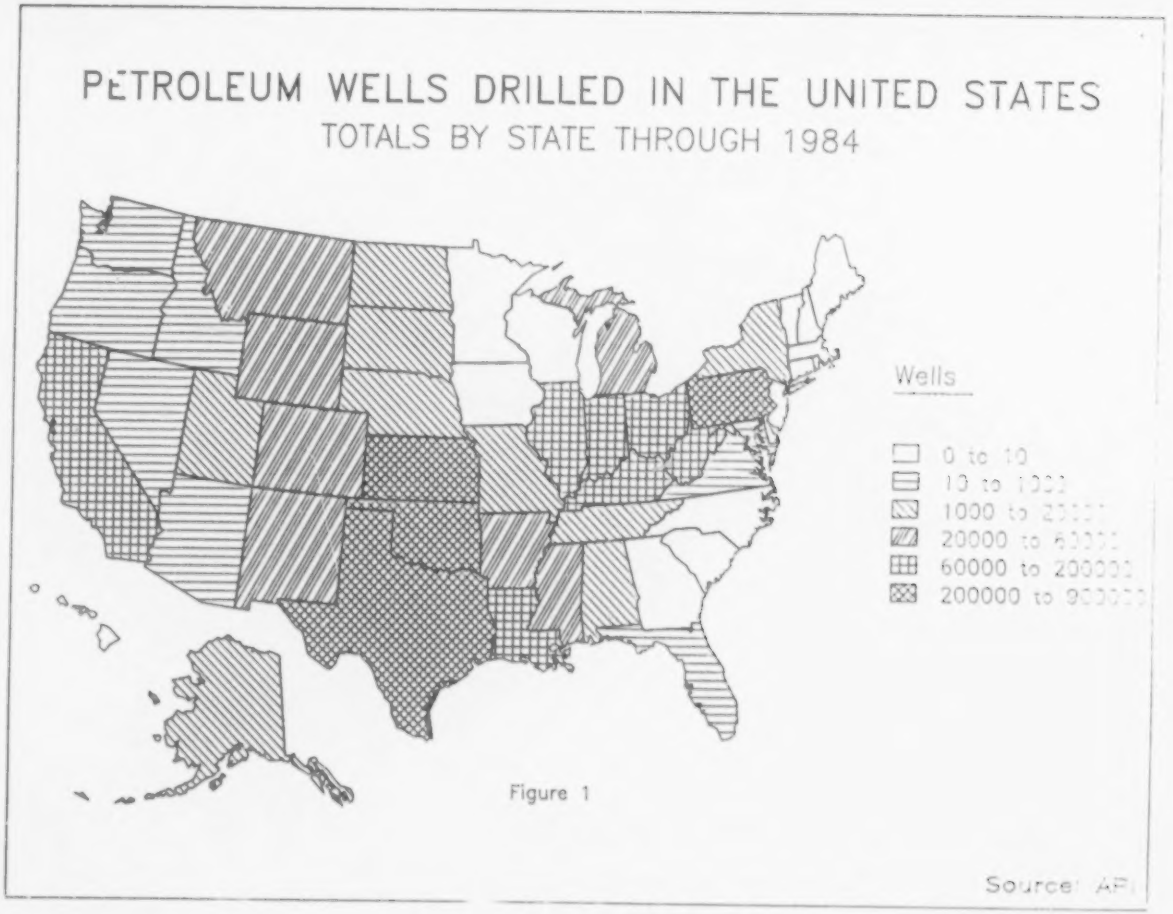
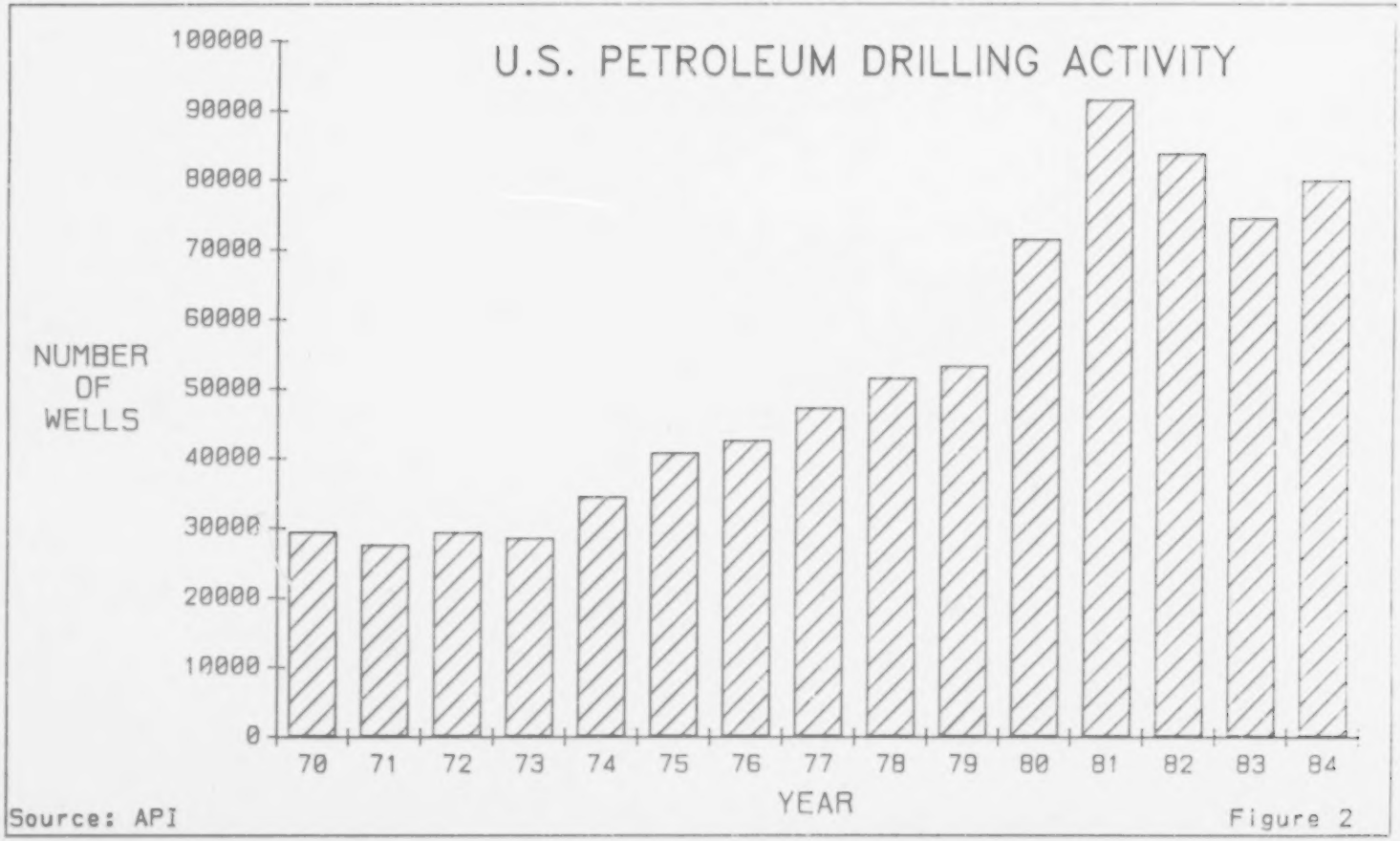

PETROLEUM WELLS DRILLED IN THE UNITED STATES
TOTALS BY STATE THROUGH 1984
Wells
0 to 10
10 to 1000
1000 to 20000
20000 to 60000
60000 to 200000
200000 to 900000
Source: API

Figure 1



Source: API

Figure 2

same time period, fewer than 200,000 wells were drilled in the remainder of the free world.

Unfortunately, similar information is not available for the other categories of drilling activity. However, it is safe to assume that the number of water wells exceeds that of petroleum. The number of holes drilled for nonfuel mineral development is somewhat smaller, but many of the areas of such development are separate from areas of petroleum exploration. Therefore the data derived from drilling for nonfuel minera.. are important sources of subsurface geological information.

Thus, from these drilling activities a large amount of information has been accumulated that is essential in developing a knowledge of the geology of the earth's shallow crust in North America. Such information permits us to define with substantial accuracy the location and configuration of the major sedimentary basins of the United States and to describe the geology of some in remarkable detail. Somethat less abundant but nevertheless important information is available to describe those portions of the earth's shallow crust at the margins of and between the sedimentary basins. Information thus obtained from drilling, used in conjunction with seismic profiles and other geophysical data, is critical to the emerging interpretation of the geology of the earth's shallow crust in North America.

It is appropriate to ask the question "Why does the Nation need a Continental Scientific Drilling Program if we have such a large data base from other drilling activity?" The answer is that it is precisely that data base that makes the proposed national program both needed and feasible. Based upon the analysis of drill data and other information collected over the better part of two centuries, a number of areas have been identified where the drilling of dedicated holes has a high probability of producing information needed to improve our geologic understanding of the earth's crust in North America. However, we cannot expect to obtain the needed drilling data for these identified areas from either the petroleum or nonfuel minerals industries. The

areas in question do not have high economic potential based upon current knowledge and are therefore not expected targets for industry drilling. Furthermore, at least for the near-term future and, in my opinion, for the foreseeable future domestic drilling for petroleum will be confined to the lower-risk development of known resources and drilling for metallic mineral resources will be virtually nonexistent.

The United States does have a decided advantage over most other countries in the world which have or are developing continental scientific drilling programs, because we have the most extensive data base in the world from which to begin this endeavor. For example, there have been more petroleum exploration and development wells drilled in the State of Texas than have been drilled in the rest of the world. Furthermore, the number of petroleum wells drilled in either Oklahoma or Pennsylvania exceeds that of any other country in the world. The use of the resulting wealth of well-history information will facilitate the development of a well-focused, cost-effective Continental Scientific Drilling Program.

There are numerous benefits to be derived from such a program. First and foremost are the obvious scientific benefits that will be derived from a better understanding of the earth's continental crust. Consider, for example, the results of the deep sea studies that have been conducted for the past three decades. Geophysical investigations together with almost two decades of an extensive ocean drilling program have revolutionized our understanding of the geology of ocean basins. The theories of plate tectonics were developed and tested through these investigations, leading to new explanations for the formation of ocean basins, the creation of some of the earth's most extensive mountain chains, and the emplacement of some of the richest metal deposits found to date. From these scientific investigations that have included critically important drill information, it is said that we now know more about the geology of the earth's crust beneath ocean basins than we do about the "continental" crust on which we live.

Second, application of such drill information is important in improving our understanding of a broad array of applied geological activities. For example, a deep drilling program such as that proposed for Creede, Colorado (Fig. 3) would explore the roots of an ancient hydrothermal-magma system. The data derived from such a drill hole could either confirm or modify substantially our understanding of the processes by which such major metallic mineral deposits were formed. Likewise, a deep drill hole such as that proposed for Cajon Pass, California (Fig. 3) in the vicinity of a major, currently active fault would provide critical data in support of the Nation's earthquake research program. In particular, careful determination of in-situ stress conditions and precise heat flow measurements are needed to evaluate current models of such faulting. The proposed deep hole in the Illinois Basin (Fig. 3) would explore a portion of that basin not previously reached by petroleum drilling activity. The data obtained would contribute to an evaluation of the resource potential of deep formations in the basin and would enhance our understanding of how such basins were formed on the continent. The deep hole proposed for the Southern Appalachians (Fig. 3) would investigate a major geological process of crustal deformation that produced the Appalachian Mountains, and would provide information on the possibility of deeply buried natural resources. Finally, the deep hole proposed in the region of the San Marcos Arch in Texas (Fig. 3) would investigate the deep geological conditions of an important petroleum-producing basin that was formed at what was once the margin of the North American continent. A comparison of the findings of this drill hole with those of the Illinois Basin should improve our understanding of the geological processes responsible for the formation of basins in two different geologic environments.

Many other examples of application of deep drill information could be cited where substantial public value could be realized. Clearly such a program will contribute importantly as well to an improved understanding of the Nation's natural resource base and such information may be critical in matters of national security and maintaining a

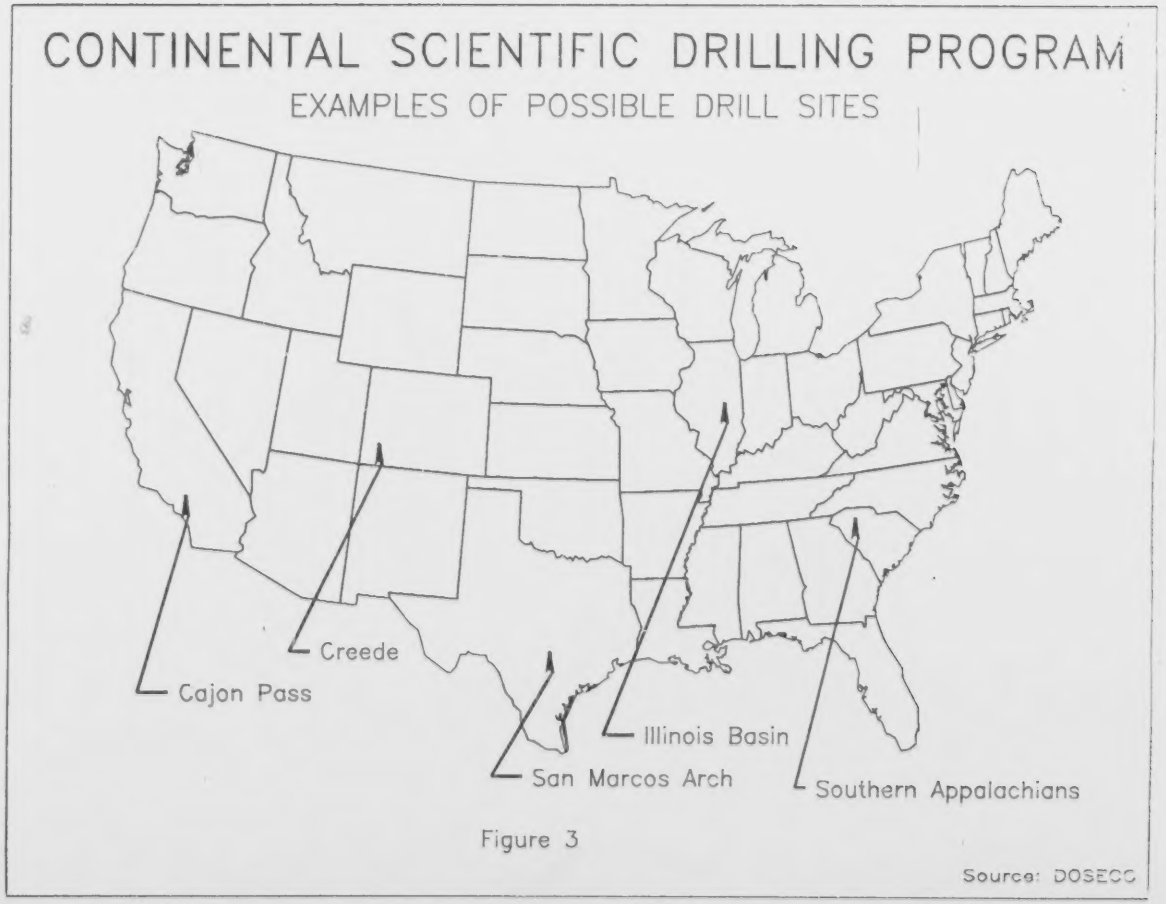

CONTINENTAL SCIENTIFIC DRILLING PROGRAM
EXAMPLES OF POSSIBLE DRILL SITES
Creede
Cajon Pass
Illinois Basin
San Marcos Arch
Southern Appalachians
Source: DOSECC

Figure 3

healthy economy. But the main point to be made is that a broad spectrum of both basic and applied scientific objectives can be achieved with a nationally focused Continental Scientific Drilling Program.

There is a broad base of interest in and support for a Continental Scientific Drilling Program. Scientists and engineers from a majority of the Nation's leading research universities and state geological surveys have been quick to convey their interests in this endeavor. The scientific plans for the several drill holes under consideration were developed through planning sessions involving academicians, federal and state government scientists, and industry personnel. Clearly some of the Nation's most professionally qualified scientists and engineers are involved. These individuals recognize, for example, that a deep drill hole in the Illinois Basin will provide important data, some of which can be translated to other similar basins on the North American and other continents around the world. Thus, even though the drill site will produce much site-specific information, some of that information will have general application to other similar geological features throughout the earth's continental crust.

At present, the National Science Foundation, the U.S. Geological Survey, and the Office of Basic Energy Sciences of the Department of Energy have established an Interagency Coordinating Group to provide coordination where possible on each agency's scientific drilling activities. This approach is commendable and progress has been made in developing a coordinated national program. For example, all three agencies are involved in supporting scientific investigations in connection with the Salton Sea drill hole funded by the Geothermal and Hydropower Technologies Division of the Department of Energy. In addition, the U.S. Geological Survey and the National Science Foundation are jointly supporting the Cajon Pass drill hole and related scientific investigations. However, much remains to be done and, at present, the combined resources of the three agencies are inadequate to sustain a viable National Continental Scientific Drilling Program.

A national commitment is needed for continental scientific drilling. Senate Bill 1026, the "Continental Scientific Drilling and Exploration Act" is the answer. It does not establish a new bureaucracy to further this important objective. Rather, it calls upon the Secretary of Energy, the Secretary of the Interior, and the Director of the National Science Foundation to implement the objectives of the Act through the established Interagency Coordinating Group.

The Act calls for a report to the Congress within 180 days of enactment describing, among other things, both long- and short-term policy objectives and goals of the United States Continental Scientific Drilling Program; projected schedules of desirable projects; funding requirements; a description of the benefits to be realized; a recommended course of action for cooperation with the international community on continental scientific drilling; and identification of other public and private entities with common interests in the program.

The important ingredients of this Act that will enhance its potential for success are:

* A Congressionally recognized and mandated Continental Scientific Drilling Program
* An established set of important scientific objectives to be accomplished
* A Congressional mandate to the Departments of Energy and Interior and the National Science Foundation to fulfill the program's objectives through the Interagency Coordinating Group
* A required Congressional review of the program

In conclusion, Mr. Chairman and Members of the Committee, this Nation needs a Continental Scientific Drilling Program. Furthermore this legislation is needed to ensure the development of that program in a scientifically sound and cost-effective manner.

Senator WARNER. Having had the opportunity to hear from your peers, is there any further comment that any of you might wish to make?

[No response.]

Senator WARNER. If not, then this hearing is concluded. I thank each of you, individually and collectively, for taking of your time and traveling substantial distances to come and advise this committee, and indeed the Senate as a whole. I am cosponsoring this legislation with my distinguished colleague from South Dakota, and the two of us will shepherd this legislation through the Senate in an efficient and timely manner, so your energies will not have been in vain.

Thank you, gentlemen, and ladies present.

[Whereupon, at 12:29 p.m., the hearing was adjourned.]

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